

SOME MINUTE ANIMAL PARASITES

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SOME MINUTE ANIMAL PARASITES



FIG. 1



FIG. 2

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ANTI-MOSQUITO MEASURES. BRITISH GUIANA

1. OLD CANAL.—A BREEDING PLACE FOR MOSQUITOES

2. CANAL FILLED IN AND CONVERTED INTO AN AVENUE

SOME MINUTE ANIMAL PARASITES

OR

UNSEEN FOES IN THE ANIMAL WORLD

BY

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WITH FRONTISPIECE AND FIFTY-SIX TEXT FIGURES

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PREFACE

DISEASES, both of men and animals, are subjects that have come more to the fore in recent years than in the past. The present book is the outcome of our attempts made during the last few years to satisfy the numerous inquiries made to us for a scientific but readable account of the minute animal parasites that produce diseases, detrimental alike to man and beast. As the book has been framed with the idea of being of service to many different classes of readers, it is written in a semi-popular yet scientific vein. Care has been taken to explain fully the few technical terms that have been used, and to repeat these explanations.

The selection of subject-matter, naturally, has presented some difficulty, but so far as possible that side of the science of Protozoology, that comes in direct contact with human life and needs, has been chosen in preference to that which deals with the more theoretical and speculative side. Diseases of man, cattle, horses, poultry, game, fish, and bees, due to parasitic Protozoa, thus occupy a large proportion of the book.

New illustrations have been used throughout this

work, the drawings being made from our own specimens.

It is hoped that this book may be the means of interesting the science student and general reader alike in the very great economic importance of these unseen foes in the animal world, and lead to a more detailed acquaintance with them in the future.

H. B. FANTHAM,
A. PORTER.

January, 1914.

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CHAPTER I

INTRODUCTION—THE CELL—PROTOPLASM— GENERAL CHARACTERS OF PROTOZOA

THE world of Nature is a vast one, and the range of living beings is of enormous extent. Some of the most interesting organisms are those that are so small that no eye can distinguish them individually, and only when great magnification is used can their form be described, though the effect of masses of them may be only too obvious. The animal world ranges from these tiny living units, each independent, capable of carrying out every function associated with life, to the enormous aggregation of living units, welded together into the vast complex that is called an elephant or a man. In these latter no one living unit is independent, but the units are joined together in groups, each group having a special function to carry out, and performing that function mainly, and little else.

What is a living unit? Of what does it consist? If the simplest form of living animal be examined under the microscope, it has the appearance of a

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minute speck of clear, jelly-like substance, in which a somewhat denser mass is embedded. The jelly-like mass can move about and does so, sometimes very actively, at other times slowly and with a creeping movement. Always the denser part is dragged about with it.

The fluid, jelly-like mass is known as protoplasm

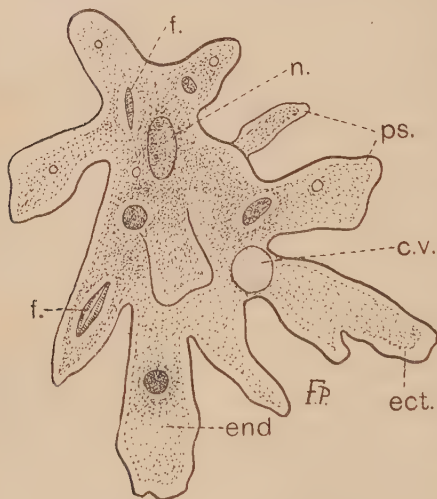


FIG. 1—AMOEBA PROTEUS

ect., Ectoplasm (outer layer of protoplasm);
end., endoplasm (inner layer of protoplasm); *n.*, nucleus; *ps.*, pseudopodia;
c.v., contractile vacuole; *f.*, food particles
 in food vacuoles

(Fig. 1), and the denser body contained within is the nucleus (Fig. 1, *n.*). This nucleus is most important, for it controls all that the general protoplasm does, and regulates the life of the tiny animal. When the death of the nucleus occurs, the whole animal

dies. It is the vital part of the living unit, and the latter is usually called a cell. Every cell consists of protoplasm and nucleus.

What are the functions of the single, living cell that constitutes the simplest animal? The minute

animal performs exactly the same processes as the complicated one. All animals must breathe, must feed, must excrete waste matters, and must increase in numbers or reproduce themselves. The single, tiny cell that constitutes the simplest animal can do all these things. Its protoplasm can absorb oxygen from the surroundings in which it lives—that is, it can breathe. It can take in and digest food, building it into new, living protoplasm. The waste products, both of its food and those produced by its own activity, are expelled from the body of the tiny organism. When need arises, it can divide into two portions each resembling itself, and so form two new individuals; or in some cases, hundreds of little organisms may be produced by its division, each growing like the parent and each capable of living like its progenitor.

Again, among some of these one-celled animals clear differences, analogous to those observed in higher animals, are found. Sex is present, even in some of these very early and primitive forms of life, and from the union of male and female one or more minute progeny arise. These, being invigorated by the union of their parents, carry on the race with greater capacity than do those organisms produced without the intervention of sex. The single-celled animals are very numerous—so numerous, in fact, that they form a large group in the animal kingdom known as the Protozoa, or primitive living animals.

The situations in which the Protozoa are found depend largely on their mode of life. As in higher communities, some of the Protozoa live free, in-

dependent lives, swimming freely in water or moving slowly over the surface of plants or of other animals, and obtaining food from the surroundings in which they live. Others have become sedentary, and while independent of their hosts so far as their food-supply is concerned, derive the immense advantage of transport from place to place by attaching themselves to the exterior of some more active animal. With the sedentary habit, the necessity for development of means of locomotion has come to an end, and as a result, the Protozoön degenerates and its structure then appears simpler than that of its more active relations. The final degradation of the protozoal world is reached when the habitat of the Protozoa of economic importance is described. These tiny organisms are so degenerate that they have become parasites, deriving their nourishment from the body of the living animal to which they have attached themselves, and are incapable of prolonged existence apart from their host except in specialized form.

The ways by which parasitic Protozoa gain access to their hosts are of considerable interest. A large number of these organisms, towards the end of their life-cycle as individuals, become small bodies which are rounded or oval, have great powers of endurance, and are thoroughly adapted for life outside the body of the host. These forms may be termed resting or resistant stages. Many of the parasites possessing resistant forms are spread from animal to animal in a very simple way—namely, by the new host swallowing food or drink contaminated by the resting stages of the parasite. These resting bodies

have been expelled from the body of a former host. The method of infection is said to be a casual or contaminative one, and there is always the possibility of the resting parasite never resuming activity owing to it never being absorbed with food by the host, together, of course, with the equal possibility of its rapid transfer to another higher animal.

Three variations of the casual method of infection may be encountered. In the first case the parasite does not inflict serious damage directly upon the host, but injures the larger animal by depriving it of a small amount of nourishment. Certain parasitic Protozoa, known as Gregarines, live in the alimentary tract of some marine worms without damaging the food canal itself. They are free in the cavity or lumen of the intestine, migrate throughout its length, and absorb nutritive substances from the mass of food with which they are in contact.

Other members of this same group of Protozoa, the Gregarines, not content with simply absorbing raw food, seek to obtain some food already manufactured. To secure this, one end of the body of the Protozoön becomes applied to the wall of the gut, and may even bore in between the elements composing it. Consequent on this action, some of the living protoplasm is destroyed, and the almost liquid contents of the injured cells pass into the parasite. The portion of the Protozoön which is between the cells serves thus the double purpose of securing the parasite as it feeds, and of aiding in the feeding process.

Yet a further stage of dependence is found in the case of the parasites (*Coccidia*) causing the disease

of grouse and other game-birds and poultry, popularly known as "white diarrhœa." Here the resting forms of the parasite are taken up with food or drink and thus pass into the food canal of the host. When the parasites reach the intestine, the living germs within are set free by the powerful digestive juice softening the outer walls in which they are enclosed. Life as free forms in the cavity of the gut soon would probably be fatal to these young organisms, which are the primary infecting germs, and they at once proceed to bore a way for themselves into the delicate lining of the alimentary canal. Here they grow at the expense of the living substance that harbours them, and as they increase in size, the host cells in which they are contained gradually die. Multiplication of the parasites within the tissue occurs, and finally the gut is reduced almost to a pulp, literally riddled with parasites. The parasitism, then, is within the tissue cells or is intracellular, and is far more effective for the nourishment of the parasite—and incidentally for the destruction of the host—than the results of the two preceding casual or contaminative methods of infection.

Leaving the casual method, a reference may be made to the annoyance caused by the stab of a gnat or mosquito, and to the effect of the stab. For many years, the malady known as malaria was invariably said to be caused by swamps, and could be avoided when the habitations of the people were well above the sea-level. It is still true that swampy or marshy conditions favour malaria, but only because the young "grubs," or larvæ, of mosquitoes live in

water, and it is by means of the stabs of the adult mosquitoes that malaria is spread from man to man. The minute parasite that invades the blood of man undergoes part of its development in the stomach of the mosquito, whence it works its way into the mouth glands, known as salivary glands. When the insect pierces the human skin in order to suck blood, the piercing organ, known as the proboscis, is moist with the saliva from the mouth. In the saliva are the active parasites. The proboscis acts like a surgeon's needle, and the parasites of malaria are passed or inoculated by it into the man. This mode of infection is known as the inoculative method.

Malaria is not the only malady transmitted by the bite of insects. Just as the mosquito is the intermediary between man and man in connexion with the malarial parasites, so are the somewhat large flies known as "tsetse" to the natives of West Africa, the Congo, Uganda, and South Africa, in relation to human sleeping sickness and cattle tsetse or fly disease. The stabbing proboscis is laden with germs of disease from the saliva, and by its action the latter are transferred direct to their victim.

Again, the inoculative method of infection is found in the case of the various tick fevers or relapsing fevers of Africa and Europe. The agents here are not flies, however, but ticks. Redwater is a fatal disease of cattle in the United States, and East Coast fever causes great mortality in cattle in British East Africa. The herds become infected by the agency of different ticks which inoculate them with the organisms responsible for the respective diseases.

There are some remarkably interesting points to note in connexion with the transmission of certain parasites from host to host. In a few cases the parasite has become so well accustomed to its host that the reproductive organs of that host are invaded by the parasites, and the young are born infected in consequence. One of the best-known cases of the occurrence of hereditary infection is that found in silkworms, occasioning the disastrous disease known as "pébrine," which devastated the silk industry of France, before Pasteur discovered the cause and devised preventive measures. Either of the parent moths might be infected, and in that case every egg was infected with the parasite called *Nosema bombycis*, and every such egg gave an infected silkworm that died before arriving at the silk-producing stage.

Redwater of cattle is due to a minute blood parasite, and is carried from cow to cow by ticks. The infected parent tick can pass on the infection to the offspring, and the latter are the great agents in spreading the disease among cattle.

A more human interest attaches to the ticks that infect man with African relapsing or tick fever by means of their excretions. The organisms causing these maladies are spirochætes, and the ticks that usually transmit them are the very young ticks or nymphs. The nymphs are so small that they are easily overlooked. Each individual, about the size of a very small pin's head, has the appearance of a small fragment of sawdust, which it resembles in colour and spikiness. Both the nymphs and their bite are very minute and easily overlooked,

or never noticed. But tiny as they are, they were hatched infected, and by their bite the spirochætes pass into man in the fluid excrement that enters the wound.

In Europe and America sheep are sometimes infested with a skin parasite, popularly known as a "sheep ked." This is really a wingless fly, *Melophagus ovinus*. It harbours a parasite that primarily belongs to the alimentary canal, but it may leave the gut, enter the ovaries, and penetrate the eggs. The eggs develop within the mother into a grub, which is passed from the mother as a sort of chrysalid or pupa. As the eggs are infected, the puparia also are infected, and when the fully developed insects emerge in the wool of the sheep, they, too, contain the parasites known as *Crithidia melophagia*. Here undoubted hereditary infection occurs, though the adult insects may become infected by the casual methods mentioned before.

The main means by which protozoal diseases are spread have already been indicated in the foregoing section. But it must be noted that in many cases the method of transmission of parasites from one host to another is almost unknown. It is only recently that much attention has been given to the subject, and the work demands rigorous and laborious attention.

Two principal classes of animals appear to act as transmitters of protozoal diseases. Leeches are the chief agents in the transference of protozoal diseases of fishes and amphibia, while insects and ticks are responsible for the spread of parasitic diseases of

mammals, birds, and reptiles. Casual or contaminative methods of infection are responsible for many maladies, and fouled food-supply is usually to be suspected. A bee disease, due to a parasite, *Nosema apis*, is spread by bees eating honey contaminated by already diseased bees. Coccidiosis in poultry and game remains for years in a district once heavily infected. The grit and soil are laden with spores from the fæces of infected birds, and the resistant forms of the parasite have been shown to remain infective for a prolonged period after they have left their first host. Wind and rain are also known as active distributing agents of some diseases.

The gradual development of the parasitic habit sheds an interesting light on the evolution of certain groups. The free-living and thus more independent of the Protozoa spend their lives in either fresh or salt water. Among these are the spirochætes. Forced by circumstances or guided by choice, other spirochætes have migrated into the jelly-like organ known as the crystalline style in the food canal of certain molluscs, such as oysters. They can move about in this medium as freely as in water, but they represent an advance in the evolutionary order. Water spirochætes are ingested by other higher animals with their drink. Some of the spirochætes so taken adapt themselves to life in the intestine of their hosts, and thus are found in the alimentary canal of such birds as the grouse. Lastly, spirochætes can be ingested and pass into the bloodstream of their host, or they may be inoculated into the host's blood from the alimentary canal of some

insect or tick. Hence arise such forms as *Spirochæta duttoni* and *S. recurrentis*, the causative agents of relapsing fevers. The grades in the evolutionary scale, then, appear to be free-living organisms, inhabitants of water, invaders of the alimentary canal, parasites of the blood.

Another interesting point is that probably the more recently a parasite has been introduced into its host, the more virulent it is. In process of time hosts may become so adapted to dangerous parasites that they are unaffected by them, or affected to a less extent. Such is the case with a parasite of rats known as *Trypanosoma lewisi*. Formerly it is probable that the parasite was pathogenic to the rats in whose blood it was found. But the organism has been introduced into rats so long that the latter are now unaffected by the intruder in the majority of cases. An allied parasite, *T. gambiense*, is the cause of human sleeping sickness. It is possible that in time man may harbour the now deadly organism without fatal effects to himself. In fact, there is already some evidence to show that this happy result is being slowly consummated, for the negroes of West Africa—the original home of sleeping sickness—are less affected by *T. gambiense* than are their brethren in East Africa, where the disease has been more recently introduced.

The life-histories of parasites vary considerably, and the details and structure must be described for each individual. But one point is worthy of note here. In the life of every parasite there is a weak period, and it is then that human ingenuity can apply its resources

in the case of those parasitic Protozoa that cause the death of cattle or man. It is for the scientist to investigate carefully for the weak spot in order that the veterinarian, stock-breeder, or poultry farmer may apply the remedy, assuming that preventive measures have failed.

The grouping or classification of any set of living animals is always a matter of some difficulty, for with advancing knowledge alterations are bound to occur. Classification is but tentative, and marks the state of our knowledge for the time being. In this book only the broadest possible classification will be given. The life-histories of the organisms are the epitomes of interest, not the "pigeon-hole" artificial arrangements that the world calls classification tables.

Among the lowliest of the Protozoa are the organisms, often almost undifferentiated nucleated masses of protoplasm, whose method of locomotion is restricted to an outflowing of the protoplasm in one direction, accompanied by the withdrawal of the living substance from another part. The protruded masses are known as pseudopodia, and it is by their agency that the progression of the organism is accomplished. Little differentiation is exhibited by many of the Protozoa of this first group. They have no cell mouth, no cell anus, no food canal, no specially formed locomotor apparatus. They are slow, relatively passive, and pass their time either motionless or creeping slowly over the pond bottom, or, in the parasitic members, over the intestine of their hosts and even invade the cells of the latter for

additional shelter and food. Such are the Sarcodina, the group of which the well-known *Amœba* of pond-water—the *Proteus* animalcule (Fig. 1) of the early microscopists—and the *Amœbæ* causing human amœbic dysentery, are familiar members. Some of the free-living members of the Sarcodina secrete or form skeletons, and are founders of parts of our country in a very real sense. The chalk hills of the South of England consist of the skeletons of millions of minute Sarcodina known as Foraminifera, while the ooze at some river mouths which forms plains in certain European districts consists of the silicious remains of countless myriads of other Sarcodina known as Radiolaria. Further, these microscopic empire builders are still continuing their work and adding to the land content of the world in many parts.

Some of the most beautiful Protozoa are the group of Sarcodina called the Heliozoa, or sun-animalcules, from whose graceful bodies pass out myriads of tenuous, radiating threads, used for defence, locomotion, and obtaining food. Though their external appearance recalls that of the Foraminifera, yet, unlike the latter, they have no hard skeleton, and their fragile bodies never form deposits in the way that those of the Foraminifera and Radiolaria do.

The Mycetozoa are a group of Protozoa claimed equally by botanists and zoologists. To the botanist they are the Myxomycetes or slime fungi; to the zoologist they are animals, the Mycetozoa, a branch of the Sarcodina. It is no part of the work of the present authors to attempt to decide the relative

claims of zoologist and botanist, but we follow the lead of the authority on the subject, Dr. J. J. Lister, F.R.S., whose standing in the zoological world is beyond assail.

A third great group of the Protozoa is the Mastigophora, which includes that vast array of organisms

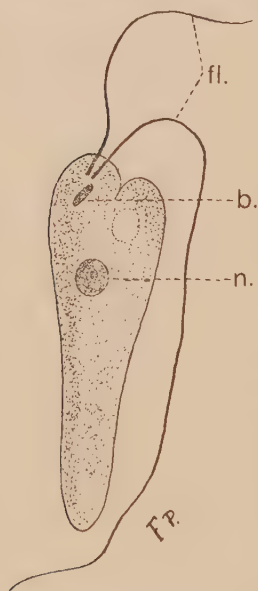


FIG. 2 — A FLAGELLATE—
PROWAZEKIA

n., Nucleus; *b.*, blepharoplast; *fl.*, the two flagella

known as the Flagellates. Within this group are both free-living and parasitic organisms, some of them being of high economic importance. The chief characteristic of the Flagellates is their possession of a special method of locomotion. Protruding from the body of the organism are one or more long, vibratile threads termed flagella (Fig. 2, *fl.*). Each flagellum is capable of rapid movements, and by means of its actions the progress of these Protozoa is largely brought about. Many of the Flagellates possess two nuclear bodies (Fig. 2, *n.*, *b.*), the functions of which are supposed to be different from

one another. In some Flagellata the limiting layer of the body is prolonged outwards into a finlike, propulsory structure known as an undulating membrane. Much variation exists among the

Flagellates. They include widely differing forms, such as the *Euglena* of pond-water, *Prowazekia* (Fig. 2) occurring in urine, the parasites of human sleeping sickness and cattle-fly disease, the trypanosomes; while *Trypanoplasma* is a biflagellate parasite of fishes and flat-worms allied to *Trypanosoma*. Also, there are natural Flagellates found in many insects. These Flagellates belong to the genera *Crithidia* and *Herpetomonas*, and a form of the latter is found parasitic in man, being responsible for the loathsome diseases Kala-azar and Oriental sore. One stage in the life-history of the parasite causing these diseases is frequently known as the Leishman-Donovan body, that name having been given before the true relationship of this phase of the organism was fully realized. The life-histories of *Trypanosoma*, *Crithidia*, and *Herpetomonas* will be discussed in detail later.

Probably more or less allied to the *Flagellata vera* are the Spirochætacea, members of which are responsible for relapsing and tick fever, fatal alike to human beings, cattle, and birds.

The largest number of pathogenic agents among the Protozoa is probably to be found among the Sporozoa. This huge section of the Protozoa is distinguished from the others by its members producing resistant forms (spores) at some stage of their existence by which they are enabled to withstand unfavourable conditions and ultimately to find their way into other hosts. The Sporozoa literally are the spore-producing animals. Among them there is very great diversity of form, move-

ment, and habitat, but the essential feature of spore formation appears in all. Again, in some members of the Sporozoa there is a high differentiation of sex shown. It is doubtful if proof of true sexual characters has been shown in the classes of Protozoa previously mentioned, and even in the remaining group of Protozoa—the Ciliates—the sexual differentiation in the form of the organism is by no means so complete as in the Sporozoa. At the same time, the whole life-cycle of certain of the Sporozoa is very imperfectly known, and in some cases asexual reproduction may be the most familiar feature in the organism's history, while the sex forms, if any, are unknown.

The Sporozoa are very varied. Among them are found the delicate malarial parasites; the more massive parasites of the blood-scavengers, the leucocytes; the wormlike parasites of the meal-worms (dear to the angler), and many other lowly animals known as Gregarines; the parasites of the alimentary canal of man, other mammals, and birds, known as the Coccidia, a group of enormous economic importance; the parasites responsible for the pébrine disease among silkworms and a similar one among bees, the parasites belonging to the genus *Nosema*; the organism *Rhinosporidium* that produces nasal and aural polypi in man; and many others. The economic importance of the group as a whole is immense, and demands much careful research and study.

Finally, the last great section of the Protozoa is the Infusoria, and it includes all the Ciliata. These organisms have the act of movement carried out by

means of a great number of fine, contractile threads or cilia. The cilia by their rapid vibration either aid in propelling the organism forwards, or else create water-currents in which the minute animal or vegetable organisms destined as food for the Protozoön become wafted to their destination—the cell mouth of the organism—for, unlike most of the Protozoa, the Ciliates are provided with a special opening, or cell mouth, by which food is taken.

The Ciliata exhibit the highest morphological differentiation among the Protozoa. Many have two nuclei, one of which only is concerned in reproduction, while the other controls

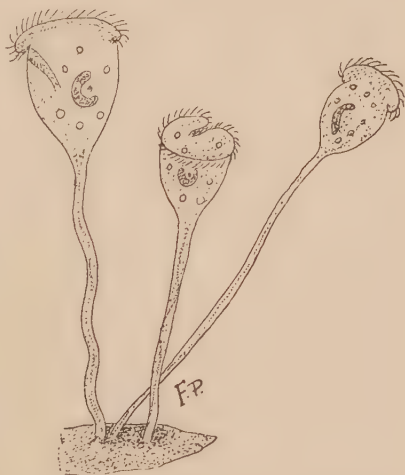


FIG. 3 — VORTICELLA, AN EXAMPLE OF A CILIATE, ATTACHED TO A PIECE OF WOOD

nutrition. Among the Ciliates are some of the most beautiful of our fresh-water organisms, the slipper animalcule (*Paramecium*) with its rapid movements, and the graceful, delicate bell animalcule, *Vorticella* (Fig. 3), being two good examples.

Having thus briefly outlined some of the characters of the main groups, the life-histories of some

of these most interesting Protozoa may now be considered. Naturally the choice of material from so wide a range of organisms is a matter of difficulty, but it will be our endeavour to select material presenting as much variation as possible, and being of interest—economic or otherwise—without reference to strict schemes of classification.

CHAPTER II

UGANDA'S SCOURGE : SLEEPING SICKNESS, OR HUMAN TRYPANOSOMIASIS

MANY of the fairest parts of the earth are unfit for the homes of Europeans on account of the presence of noxious insects, by whose bite deadly diseases are conveyed to the unfortunate victim. Among the pestiferous insects are such flies as the *Glossinæ*, or tsetse flies, responsible for the deaths of thousands of natives of West, Central, and East Africa, and for enormous monetary losses in cattle, horses, mules, and camels in Africa generally.

The minute animal parasites responsible for the diseases known as "sleeping sickness" in man and "fly-disease," or "nagana," in animals are known as trypanosomes. The first-known trypanosome was described from the blood of a fish some seventy years ago, and since that time many members of the genus *Trypanosoma* have been recorded from various hosts. As its name implies, a trypanosome is a small organism with a body capable of executing screwlike movements. The movements are rapid, and are of a peculiarly graceful, billowy character, for the trypanosome is provided with a lateral fin-

like extension of its body known as an undulating membrane. By this membrane not only is movement brought about, but a steadiness and grace are imparted to the movements which render it more smooth than that of allied organisms which are not provided with a membrane. The structure and life-cycle of the trypanosome responsible for sleeping sickness may be considered as typical.

This highly pathogenic agent (*Trypanosoma gambiense*) was discovered in its human victims only as recently as 1901 by Forde and Dutton in the Gambia, and by Castellani (1903) in Uganda. Various sleeping sickness expeditions have been sent out to Uganda by the Sleeping Sickness Commission of the Royal Society. Under the distinguished leadership of Colonel Sir David Bruce, a most important addition was made to the world's knowledge of the disease. From his previous brilliant researches in Zululand on "fly-disease," Colonel Bruce realized the possibility of some biting fly—probably a tsetse—being the transmitter of sleeping sickness, and the result of his labours in Uganda was to establish conclusively that the tsetse fly, *Glossina palpalis*, was the carrier there of sleeping sickness from man to man.

Trypanosoma gambiense is a small organism, measuring from 18 to 35 μ , or about one-thousandth of an inch long. It has a narrow, tapering, vermiform body (Fig. 4, *b.*), which is blunter at one end than at the other. Extending down the greater part of the body is a wavy extension of the body wall known as the undulating membrane (Fig. 4, *m.*).

This is thrown into a series of troughs and crests when the trypanosome is moving, and is the chief agent of locomotion. Extending along the edge of the membrane is a stronger band or thread, which stains more brilliantly than the rest of the membrane and takes much the same coloration as that of

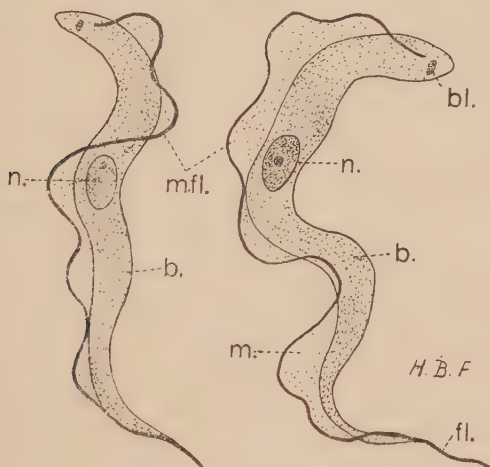


FIG. 4—*TRYPANOSOMA GAMBIENSE*, FROM BLOOD

b., Body of parasite ; *n.*, nucleus (trophic nucleus) ; *bl.*, blepharoplast (kinetic nucleus) ; *m.*, undulating membrane ; *m.fl.*, marginal flagellum ; *fl.*, free flagellum

the nucleus. This band, which may be termed the chromatic or flagellar border (Fig. 4, *m.fl.*) of the membrane, extends beyond it for some distance as a free-lashing structure known as the free flagellum (Fig. 4, *fl.*), also aiding in locomotion. The body of the trypanosome is drawn out at the flagellar end, and it is often difficult to tell where the body proper ends and the flagellum becomes free. The flagellar

end is the anterior end, but the organism can move with either end forwardly directed. The posterior end is much blunter than the anterior, and is relatively passive. Within the body are two nuclei, a large one (Fig. 4, *n.*), usually oval, and a somewhat more deeply staining smaller nucleus, termed a blepharoplast by the majority of scientific workers (Fig. 4, *bl.*). Some workers, however, consider that this second nuclear body must have some controlling influence over locomotion, because the flagellum arises in its vicinity, and so call it a kinetic nucleus. As further proof of the existence of this function is needed, it can only be regarded as an interesting suggestion or idea, especially as some trypanosomes are known in which a blepharoplast is absent. The blepharoplast is much smaller than the nucleus, and extends usually transversely across the body of the parasite, and is nearer the posterior end than the nucleus. The blepharoplast, as a rule, shows no internal differentiation until the period for multiplication by division occurs, and then it may present various forms, which will be described when dealing with division. The general body substance of the living trypanosome consists of a finely granular protoplasm, in which larger granules may be embedded.

The trypanosomes live at first in the blood of their human victim, but some very soon pass from the blood into the lymphatic glands, and thence later make their way into the fluid in the tiny canal that occupies the centre of the spinal cord, and that expands into larger chambers within the brain. The

illness during the period when the trypanosomes are found chiefly in the blood-stream is the "Gambia fever" of the earlier observers. It is when the parasites reach the spinal fluid and brain that the sleepiness characteristic of the later stages of the dread disease becomes noticeable. Throughout the progress of the infection, some of the trypanosomes pass into certain of the internal organs of the host, notably the lungs and spleen. In these backwaters of the blood-stream the parasites lose their elongate form and flagella, and become rounded. These oval or rounded bodies are known as latent bodies, and in process of time develop again into flagellate trypanosomes. The life-history of the trypanosome in its host may now be briefly described.

THE TRAGEDY OF THE GLOSSINA AND THE MAN

On the West Coast of Africa, many small settlements of white men engaged in the rubber, palm-nut, and coconut industries may be found. Apart from the settlements, there are many isolated outposts of men, some working in small parties of three or four, others singly endeavouring to wrest some of the rich spoils of the tropical African forest for the use of man. Many are the perils to be overcome by them, and not the smallest is the one that can be least guarded against, and from which Nature—"red in tooth and claw"—affords no defence. Lurking under rotting leaves, among banana roots, and in the soft shaded soil near the streams, the parent tsetse flies drop small maggots, or larvæ, which rapidly become very like the fœtid surroundings in

which they live. The hot, clear atmosphere is ideal for them, and in time the adult fly, *Glossina palpalis*, emerges, and at once desires to feed. The female fly is somewhat larger than her mate, and the desire for food is strong in both sexes, the food preferred being human blood. Flying a little inland, rarely more than about 30 yards from the water, to a village of huts, or along shore to a camp settlement or ford, the Glossinæ meet with man, and perhaps some negro, whose emaciated body, intense lethargy, and heavy breathing are evidences of his condition, is encountered. The very slight buzz of the insects does not arouse him, nor does he attempt to drive them away. They poise above him, and then, with a sudden swoop, the proboscides are plunged into naked leg or arm, and the abdomens of the flies become more and more distended as the blood of the man, heavily laden with the infective trypanosomes, passes into the flies. Gorged at last, they fly away to digest their meal. But they are satisfied for a short period only, and once more are on the wing to find a new food-source. Working along the shore, tormented by biting flies and other creeping insects, is a young European, full of energy and skill. A good host, though a black skin would be preferred! Amid other distractions, the stab of the Glossina is unnoticed, but the damage is done. As the thrust of the proboscis into the skin is made, the wriggling trypanosomes swim forwards into the blood of the new host. At first the parasites are very few in number, but ere long they grow rapidly, and commence to multiply by longitudinal division. The

blepharoplast shows the first signs of division, for its substance gradually concentrates into two masses, so that it looks like a dumb-bell. The root of the flagellum splits into two, and the split extends to the undulating membrane and the free flagellum, which also become divided into two. The heads of the dumb-bell-shaped blepharoplast separate, and the nucleus becomes constricted and divides into two also. Meanwhile, the activity of the two daughter flagella is very great; they exercise a pull on the body, and gradually diverge from one another. The split extends backwards, much in the way that blades of scissors diverge from one another, and finally the two daughter organisms lie in a straight line and then completely separate into two, each practically a thin replica of its parent. Occasionally the division occurs in such a way that the daughter organisms are unequal in size, and in consequence of this and of growth, the greatest possible diversity of form occurs. However, two principal types may be distinguished—namely, long, thin forms (young) and shorter and broader, stumpy forms (mature). The parasites grow and multiply in the manner outlined above with the greatest rapidity. Generation after generation of trypanosomes succeed one another; the blood of the man swarms with them, and he shows dullness and fever. Then the man commences to struggle against the parasites, and the latter retreat to the internal organs, especially the lungs and spleen, of their victim. There the protoplasm of the parasite concentrates around the nucleus and blepharoplast, the flagellum shortens as

part of its substance is withdrawn, the membrane becomes merged in the body, and gradually a clearer



FIG. 5—DIAGRAMMATIC REPRESENTATION OF THE FORMATION OF NON-FLAGELLATE (LATENT) BODIES OF *TRYPANOSOMA GAMBIENSE* IN INFECTED RAT'S BLOOD, AS SEEN UNDER THE MICROSCOPE ON A WARM STAGE DURING A PERIOD OF THIRTY MINUTES

area makes its appearance around the part containing the nuclear bodies (Fig. 5). This clear area shows as a bright shining band of oval contour when the parasite is examined under the microscope. Gradually the shining area hardens, for it is really a very thin protective coat in the making, and the parts of the body not required are left outside it, and simply disintegrate. The oval or rounded bodies thus produced remain

relatively in the same place as where they were formed, and consequently do not occur in large

numbers in the general circulation. Examination of the man's blood at this period may show very few or even no trypanosomes, but within the internal organs the oval, latent bodies remain. After an

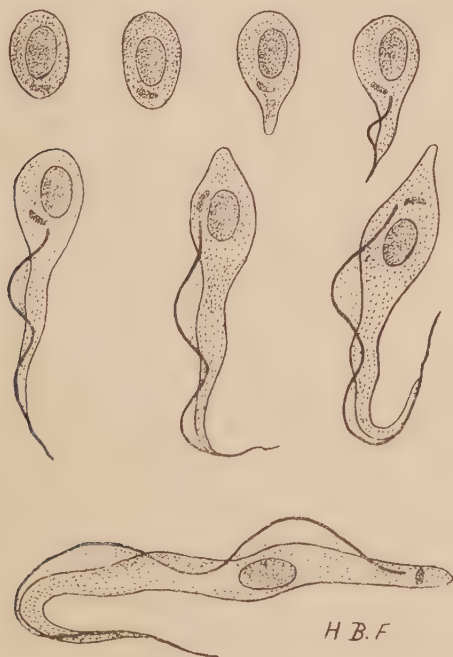


FIG. 6—DIAGRAMMATIC REPRESENTATION OF THE METAMORPHOSIS OF A LATENT OR NON-FLAGELLATE PARASITE INTO A FLAGELLATE TRYPANOSOME (*T. GAMBIENSE*)

The time taken for the metamorphosis was about one hour

interval of rest, the recuperated parasite begins to grow again (Fig. 6). The latent body becomes more elongate, and its nuclei less near one another. A special change is noted near one end. Here a

threadlike portion forms near the blepharoplast, and gradually this thread, or flagellum, reaches the surface (Fig. 6), pushing the outer layer before it, and so producing the characteristic undulating membrane. The posterior end lengthens at the same time, and ere long the trypanosome has fully formed, and swims away into the general circulation. Some trypanosomes ultimately find their way into the cavities of the spinal cord and brain, and there continue their activities, producing the sleepiness that deepens and deepens until it reaches the infinite sleep of death.

In spite of the enormous difficulty of the work, the formation of the latent bodies from the flagellate trypanosomes and the growth of the latent bodies into the flagellate forms has been observed in the living organisms by one of the present writers (H. B. F.), who described the processes fully in a paper read before the Royal Society in December, 1910, and published in the Proceedings of that Society in 1911.

In 1910, Sir Ronald Ross and Dr. D. Thomson counted daily the number of trypanosomes present in definite quantities of the peripheral blood of a patient, and plotted a curve, showing the relations of the daily numbers. They found that every seven days there was a crest in the curve, showing that the number of trypanosomes reached a maximum every seventh day. After this there was a decrease to a minimum, and then again an increase to a maximum. This same periodic variation in the numbers of flagellate trypanosomes was found to occur in

rats, guinea-pigs, and rabbits by Drs. Fantham and J. G. Thomson. Dr. Fantham also explained the periodicity.

When a *Glossina palpalis* bites a man, only a few trypanosomes can pass into the human circulation as a result of the bite. For the perpetuation of them, increase was necessary, and consequently rapid multiplication of the parasites by longitudinal division occurred. This continued for some time, and the first crest of the curve was reached. As a result partly of the reaction of the host on the parasites, and also of the over-vigorous multiplication of the parasites themselves, some of the trypanosomes die and their bodies degenerate. Others show resistance, retreat to the internal organs, and there, withdrawn from the general circulation, become latent bodies. Consequent on these two causes, the number of trypanosomes in the peripheral blood decreases to a minimum. With the diminution of resistance on the part of the man or other infected vertebrate, the re-formation of the flagellate trypanosomes commences, and is followed by division. Again, an increase in the number of flagellates in the peripheral blood occurs, and the curve plotted shows a gradual rise, until at the period of the seventh day in man the maximum is reached, only to be followed by a gradual decrease in numbers, and corresponding descent of the curve as the trypanosomes gradually disappear from the peripheral circulation. Thus does the careful observation of morphology elucidate the puzzling periodicity in numbers obtained by the enumerative methods.

To complete the life-story of the trypanosome as far as it is known at present, the period passed by it in the fly must be considered. Recent work on this subject has been published by Sir D. Bruce and his colleagues, and Miss Robertson. After detailed examination of many infected flies, these workers concluded that many of the *Trypanosoma gambiense* remain largely unchanged except for multiplication during the period that they are within the alimentary tract of the fly, or in other words, that many of the parasites keep the trypanosome shape and appearance in the fly. When the parasites reach the salivary glands of the tsetse, they become somewhat stout or stumpy, and then present the appearance of the stout trypanosomes found in the circulating blood, and in this form they are inoculated into the next victim who is bitten by the fly.

A remarkable feature in the life-history of the trypanosome in the fly is the fact that the trypanosomes seem to disappear very soon in the flies, which are not infective for more than a short time after feeding. But about twenty days after the first feed of infected blood the fly again becomes capable of infecting a fresh host, and may remain infective even for the rest of its life—at any rate, up to one hundred days. This remarkable fact of delayed infectivity of the tsetse was first demonstrated by Kleine. During this period the trypanosome is undergoing development in the tsetse fly.

However, the traveller in the tropics may be assured somewhat by the fact that in Nature only about 1 per cent. of the *G. palpalis* are infected with

the sleeping sickness parasite, and also that in the laboratory experiments, when flies were fed on infected animals, in about 92 to 95 per cent. of the infected flies the trypanosomes died out completely, and the germ carriers became harmless again. A point worth noting in connexion with these experiments was that when a fly was interrupted in its feed from an infected animal, it was infective to a clean animal on which it next fed. The possibilities of repeated infections by means of a single fly thus are exposed.

The tsetse fly that carries the deadly *Trypanosoma gambiense* is not a very conspicuous object. *Glossina palpalis* is slightly larger than an ordinary housefly, and has a blackish-brown body. The under side of the abdomen is pale, while the upper side cannot be seen when the fly is at rest, as the brownish wings close over one another, and lie flat on the back. The head has a very prominent proboscis. The tsetse fly does not lay eggs, but within her body a yellowish, footless maggot develops. When this is passed from the body of the parent, it creeps into the soil, and becomes dark in colour. In hot weather the perfect fly may emerge from the pupa case in seventeen days, but should the weather be cold, as long as two and a half months may elapse between the pupation and the emergence of the fly. One female produces eight or nine young successively, and no more.

In connexion with the transference of the disease a few points in the habits of the *Glossina* may be noted. In the first place the diet of the tsetses does not consist solely of human blood; in fact,

some may go through life without ever imbibing the blood of man. Cattle, large and small, big game such as antelopes, small game, and even birds, serve as feeding-grounds for the adult flies, while decaying roots, leaves, fruits, and other vegetable and animal débris serve as shelter for the pupæ. Again, the tsetse does not need to feed so often as do some other insects, such as the Anopheles, that carry malarial parasites, and consequently the risk to human life from the bite of infected Glossinæ is rather less than the risk of malaria incurred by inhabitants of mosquito-infested areas.

Another important point is that the *Glossina palpalis* and other members of the genus frequent places where there is an abundance of moisture. Some three hundred years ago, the Elizabethan sailors learned in tropical America that a golden rule for avoiding fever and ague was to live as high in the hills as possible and to avoid the streams, and particularly the swampy lands at their margins. The same idea applies in tropical and subtropical Africa to-day for avoiding sleeping sickness. The tsetse is rarely found higher than 4,000 feet, but, intersected as the country is by streams and lakes, there is ample opportunity afforded for the breeding of the Glossina larvæ and pupæ that develop into the biting flies conveying the dread sleeping sickness from man to man, the fell complaint often called "Uganda's scourge."

Strenuous efforts have been made by the British Government to decrease the peril by dealing with the breeding-places and haunts in which the flies

multiply. In some of the most fertile areas the thick scrub that fringes the margin of the streams and lakes, and so affords cover for myriads of flies and breeding-grounds for their young, has been destroyed. Already much good has been done by the compulsory clearing of wide strips of bush along the streams, and the lack of cover for the flies has led to a decrease in the number of fresh cases of sleeping sickness. In some cases a quite secondary result has been obtained. The cleared strip has been extended farther from the water, and part of it planted with low-growing food-plants. This vegetation is not dense enough to afford cover to the tsetses, and the increased quantity of food thus available for the use of the natives has proved a valuable addition to the supply obtained by their somewhat primitive methods.

The flying habits of the insects also are worthy of note. When the atmosphere is humid, then the insects sally forth in search of prey. Again, during the hotter parts of the day, when the temptation to expose the limbs to whatever slight breeze is available is almost irresistible, the *Glossinæ* are alert and active, and for safety's sake comfort must be sacrificed by European and native alike. As many of the natives reduce their clothing to a minimum, they are naturally more liable to insect-bite than are clothed men. However, *Glossina palpalis* has been proved to be able to bite through clothing, though they rarely attempt it. Further, *G. palpalis* is known to have a strong preference for a dark-skinned victim, and hence whites accompanied by natives are rela-

tively free from flies, while their dark companions harbour numerous flies whose tint strongly resembles that of their hosts. White clothing also seems to repel the flies. When there is much wind or the sky is very overcast, the flies abandon man and invariably seek cover.

Various attempts have been made to find some ointment noxious to the fly but harmless to man. Among the African natives the juices of certain herbs rubbed on the body are said to deter the flies, but when put to the test these are of little use for any length of time. Various preparations have been used by Europeans, but practically none of them have been of effect after about an hour. Among some of the substances advocated, but which need to be renewed at frequent intervals, are eucalyptus oil, turpentine, oil of bergamot, clove oil, oil of origanum, thymol or carbolic acid in weak solution, and citronella oil, the latter seemingly being the best. Bird-lime made from mistletoe and other berries has been used for trapping flies, but is of very local service.

Regarding treatment of sleeping sickness, little can be said with certainty except that drugs containing arsenic are of most value, and that their efficacy is multiplied tenfold if the patient can be treated as soon as possible. Unfortunately, the date when a person has been bitten cannot always be determined with certainty, and the difficulty of medical treatment is intensified in consequence.

The earlier workers on the treatment of sleeping sickness used mixtures containing arsenious acid or

sodium arsenate, and Dutton and Todd in the Congo used that form of arsenious mixture known as Fowler's solution. Later, in 1905, Dr. Wolferstan Thomas treated some human patients at Liverpool with the organic compound of arsenic known as atoxyl, and though other arsenic compounds have been used since, yet atoxyl treatment probably remains one of the best hitherto devised. Arsenophenyl-glycine and arseno-benzol, otherwise known as salvarsan and "606," have also been tried, but the latter has not been a success in the treatment of sleeping sickness, though valuable in the treatment of certain other tropical diseases. Antimony also has been used, either in powdered form as the metal or in compounds such as tartar emetic, or in other organic compounds, unfortunately often without very encouraging results. Further, complicated drugs of the benzidene and benzo-purpurin series, such as trypan red and trypan blue, have also been tried, sometimes alone, sometimes in mixtures with the other compounds mentioned previously; but so far they have not been a success.

A matter that now demands the most serious consideration is the possibility of the spread of sleeping sickness to other parts of Africa. Two main roads are open to invasion—Egypt on the north, and Rhodesia or Nyasaland on the south. Much increase in the commerce of West Africa, the Congo, and Central Africa, has occurred of late, and the possibility of the infection spreading to other tropical regions such as South Asia by means of ships needs careful attention. South India in particular is in

danger, for it is from that region that thousands of coolies are imported to work rubber plantations both in Africa and in Malay. After a short period, often only of about six months' duration, the coolies consider that they have "got rich," and insist on repatriating themselves. They return to their native land, and more than one may carry away the beginnings of insidious diseases. Consequently, the Indian authorities exercise great care in preventing infected persons from landing, and in scrutinizing certain kinds of vegetable cargo for possible pupæ of *Glossina palpalis*. A *Glossina*, *G. tachinoides*, is also known in Arabia.

Unfortunately, the seriousness of affairs was not realized in time, for another kind of sleeping sickness has comparatively recently been discovered in Rhodesia, and has already claimed its toll of European victims. Again, too much attention may be said to have been focussed on *G. palpalis* as the carrier of disease. *G. palpalis* is not found in all the areas where sleeping sickness occurs, nor is it certain that *Trypanosoma gambiense* is conveyed from man to man by *G. palpalis* alone. In fact, evidence is accumulating to show that some other biting insect, probably also a *Glossina*, may occasionally transmit the parasite by its bite. In Rhodesia, at any rate in parts, *G. palpalis* is unknown, but two nearly allied *Glossinæ*, *G. morsitans* and *G. fusca*, are present in large numbers, and these flies are known to bite both man and beast.

Recently (1910) a young Englishman arrived at Liverpool suffering from a form of sleeping sickness,

but presenting somewhat different symptoms from the ordinary type, in that the ultimate sleeping stage was not well marked. Detailed examination by Drs. Stephens and Fantham of the trypanosomes present in the blood revealed the fact that the fatal

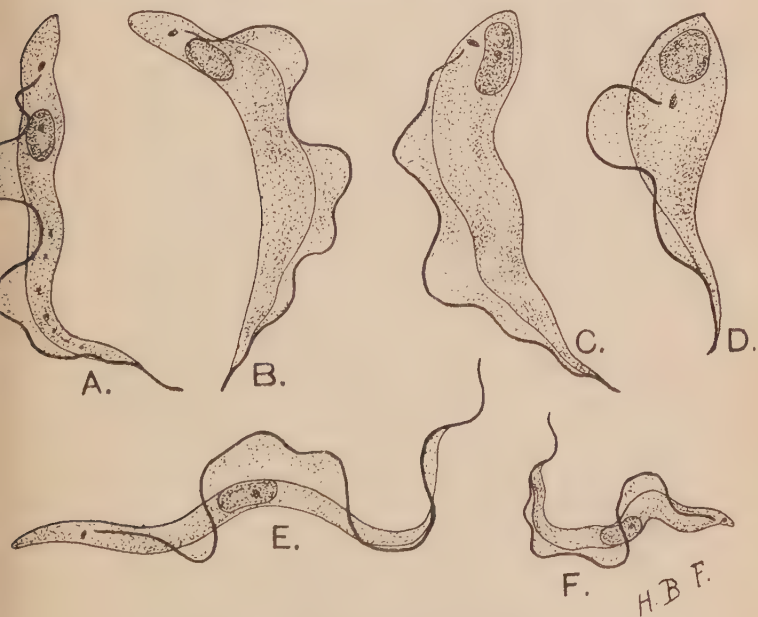


FIG. 7—*TRYPANOSOMA RHODESIENSE*

A-C, Forms showing nucleus approaching the posterior end; D, trypanosome with posterior nucleus; E, F, long and short forms with pointed flagellar ends ("snout" forms)

organism had a different structure from the form so well known in West Africa and the Congo. The parasites at times had a peculiarly elongated posterior extremity that resembled a long snout, and the "snout" forms (Fig. 7, E, F) were almost enough to

differentiate them from ordinary *T. gambiense*. But, in addition, a well-marked and very important feature was that about 6 per cent. of the parasites had the nucleus posterior (Fig. 7, *A-D*) and not in the usual central position. These trypanosomes with posterior nuclei were stout and stumpy (Fig. 7, *D*). Because of both its extraordinary virulence and its structural differences, the parasite must be considered as a new species, and consequently it was named *Trypanosoma rhodesiense*, after the country in which it was first reported. A further reason for the creation of a new species was that, so far as could possibly be ascertained, the patient had never been in a district where *G. palpalis*, the transmitter of *T. gambiense*, was known to occur. However, the man had frequently been exposed to the bites of *G. morsitans*, and in one district through which he had passed, *G. fusca* was present. Consequently the inference was forced upon the investigators that a new carrier of the new parasite had been working, and that *T. rhodesiense* had been transmitted either by *G. fusca*, or more probably by *G. morsitans*. Next a cable stated that Dr. Kinghorn had just proved the accuracy of the inference of Stephens and Fantham by transmitting *T. rhodesiense* by *G. morsitans*. Two additional reasons for the creation of *T. rhodesiense* have been afforded by a biometric study of the parasite and by cross-immunity experiments, both of which show difference from *T. gambiense*.

Since this first case of *T. rhodesiense*, other cases from Rhodesia have been reported, and also victims have been found in Nyasaland. The life-history of

T. rhodesiense in its human host follows the same cycle as *T. gambiense*, and produces latent bodies resembling those of the older-investigated parasite. Further work by Kinghorn and Yorke in Africa has shown definitely that certain big game—antelopes, bushbuck, etc.—harbour *T. rhodesiense* without themselves being affected by it. But flies feeding on such big game get infected and are capable of transmitting the trypanosome to man. It may be mentioned that earlier laboratory experiments had been made to determine whether tsetse flies other than *G. palpalis* can transmit *T. gambiense*, and the work of Taute has shown that *G. morsitans*—a widespread tsetse—can act as a carrier, while that of P. H. Ross has in a single instance inculcated *G. fusca*.

The preventive methods advocated in connexion with the spread of sleeping sickness may be briefly summarized. Supervision of the journeys of travellers from infected districts should be strict, particularly where natives, who are known to be followed by tsetses, are concerned. Persons suffering from sleeping sickness should be removed from the belts frequented by the flies to places where they are not liable to be attacked and so become new sources of infection. Villages in the fly-belt, where necessary, should be destroyed, and their inhabitants removed under supervision to fresh quarters, a matter of some difficulty. It is also important that big game, which act as reservoirs of disease, should be kept down to a much greater extent than is the case at present.

For the better protection of Europeans, their

quarters should be as far away as possible from those of the natives, nor should the native water-carriers be allowed entrance into the European houses, nor, if possible, into their compounds. White clothing preferably should be used, as it is the colour most disliked by tsetse.

Clearing of the bush along the water's edge for at least 30 yards, and around the villages for at least 100 yards, should be compulsory, and the clearings should be maintained.

A remarkable new trypanosome, called *Trypanosoma* or *Schizotrypanum cruzi*, has recently been described by Chagas from South America, in cases where children have died in large numbers. The infection caused by *T. cruzi* attacks the whole population, so that children born in the place sicken in their first year of life, and either die or become chronic victims, and a continuous source of spread of the disease. Acute disease seems to be almost exclusively among young children, except in the case of new-comers to the infected districts. In the acute form there is continual fever, swelling of the glands generally, with enlargement of the thyroid gland (near the "Adam's apple") in the throat, and frequently symptoms of meningitis. Loss of hair occurs in older children up to the age of fifteen years, and a peculiar bluish-bronze pallor appears. The expression of the victim is markedly dull and heavy. In native adults the disease usually runs a chronic course.

T. cruzi (Fig. 8, A, B) is distinguished from other human trypanosomes by the fact that the

rounded form of it can divide into a number of very small forms, the division occurring especially in the lungs (Fig. 8, C-F), and other internal organs and

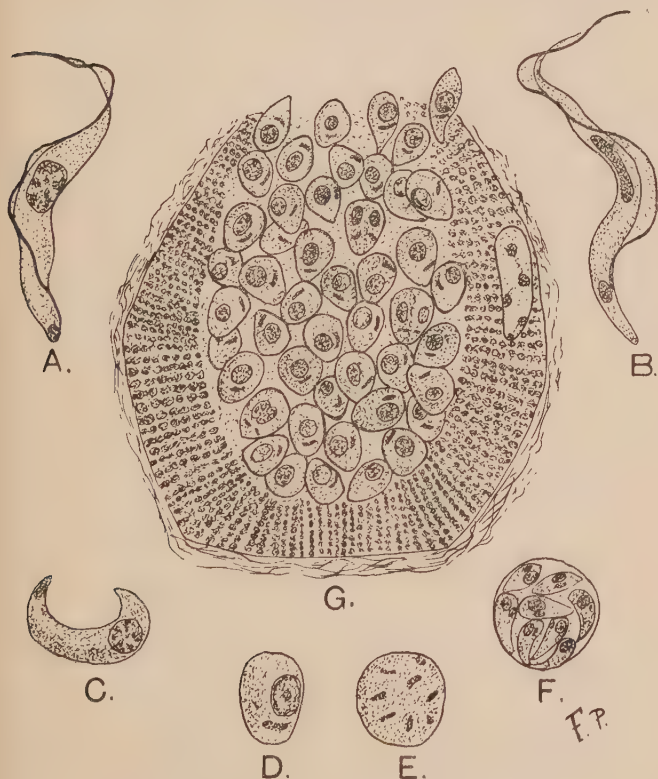


FIG. 8—*TRYPANOSOMA* (*SCHIZOTRYPANUM*) *CRUZI*

A, Stout form of flagellate in the blood; *B*, more slender type of blood flagellate; *C*, contracted trypanosome preparing for schizogony; *D*, uninucleate schizont from the lungs; *E*, mother form showing nuclear division (from the lungs); *F*, schizont with eight merozoites (daughter forms); *G*, transverse section of striated muscle with its centre filled with *T. cruzi*

tissues (Fig. 8, G) of the sufferer. There is a likelihood that a simple division into two of the rounded bodies of *Trypanosoma rhodesiense* and *T. gambiense* occurs. But *Schizotrypanum* seems to have gone a step farther. It has introduced multiple division or schizogony into its life-cycle, and immediately after its recuperative rest, has proceeded thus to reproduce the race with a vigour not displayed by the better-known trypanosomes. It is of interest to note that *T. cruzi* is transmitted normally by the bug *Triatoma* (*Conorhinus*) *megistus*.

Such is a short outline of the life-histories of the parasites responsible for human trypanosomiasis. We may now pass to a brief survey of the trypanosomes of other animals and of some other allied parasitic flagellate Protozoa.

CHAPTER III

SOME OTHER TRYPANOSOMES AND ALLIED PARASITES

THE human races are not the only victims of trypanosomiasis. The disease may occur with more or less disastrous results in many domestic animals, such as cattle, horses and camels; in the big game of Africa, where bushbucks, antelopes, gazelles, gnus, and other hoofed animals are affected; in birds, reptiles, amphibians, and fishes.

Those pioneers of travel and industry to whose efforts the opening up of Africa was due, were hampered at practically every step by the death of their transport animals. Horses and oxen alike fell victims to the "fly" or "tsetse disease," and even mules, asses, and dogs sometimes were attacked and succumbed to the same pest. The pioneers in Zululand recognized the difficulty, and that the continuous destruction of their means of transport was fatal to the development of the industries of the land. In 1894 Sir D. Bruce investigated the problem of the fly-disease, or "nagana," in Zululand. The "fly-belt" was the tract of country that meant death to horses or cattle crossing it, and it was

known to be infested by the tsetse, *Glossina morsitans*, dreaded by native and trader alike. Examination of the blood of the infected animals showed the presence of numerous trypanosomes, and the parasite was named *Trypanosoma brucei* in 1898 by Drs. Bradford and Plimmer, in honour of its discoverer.

The structure of *T. brucei* and several other mammalian trypanosomes resembles that of *T. gambiense* in its essentials. The flagellum is perhaps a little longer, and the membrane sometimes rather more wavy than that of the human trypanosomes in some cases, but the life-history of the Protozoön follows practically the same course as that in man. Again, the difficulty of successful treatment lies in the administration of some drug which can not only produce degeneration of the motile trypanosomes in the blood of the host, but which can destroy the latent forms lying dormant in the backwaters of the blood-stream. The drugs previously mentioned in connexion with human trypanosomiasis have been used for horses and cattle, and with much the same results. The use of arsenic in some of these cattle diseases was advocated in the time of that great African traveller, David Livingstone.

Again, an additional trouble is provided by the fact that there are certain wild animals—antelopes, gnus, etc.—that are themselves immune to the effects of *T. brucei*, but which harbour the trypanosomes within their blood, and thus serve as living reservoirs of disease. Further, the big game are favourite feeding-grounds for *G. morsitans*. These flies gorge themselves with blood and then leave

their hosts. They rest awhile, during which period some of the trypanosomes escape digestion; but when hunger forces the flies to feed again, the big game may be miles away. Nearer at hand, perhaps, are newly imported cattle, forming a suitable food-supply. A few plunges of the flies' proboscides and the inoculation of the trypanosomes into the new host is complete. The parasites develop rapidly and the cattle succumb.

In South India railway development has been retarded to a great extent by the difficulty of transport of materials. Horses and other baggage animals are victims of a trypanosomiasis for which the native name is "surra." Certain Tabanid flies are concerned in spreading this parasite. Another noteworthy fact that has an important bearing is that surra has spread from India to Mauritius, with most serious results to the cattle and horses in the island. There is strong probability that the infected flies were imported with fodder used for the horses, and also that a few infected horses were introduced unawares. As the hosts in Mauritius were new to the trypanosomes (*T. evansi*) inoculated into them by the flies, they rapidly fell victims to the malady.

In South America trypanosomes are responsible for much loss among the horses employed on the cattle ranches. The disease, known as "mal de caderas," runs a rapid course and is usually fatal. The cause of the malady is *Trypanosoma equinum*.

Trypanosomes that have only been relatively recently introduced into their respective hosts usually are fatal to them. On the other hand, some

trypanosomes have become habituated to their hosts for extensive periods of time, and it is suggested that gradually the infected animals acquire the power of permanently resisting the deadly action of the parasites upon them, and of converting the parasite from a lethal or fatal one into a practically innocuous one. The phenomenon of a vertebrate literally swarming with trypanosomes and yet apparently in good health and performing all its normal activities is then witnessed. Such a non-pathogenic trypanosome is found in the rats of most parts of the world. This parasite, *T. lewisi*, is an organism concerning whose method of transmission there has been more controversy than has been experienced over any other trypanosome. Balancing the evidence, it is obvious that the common rat-flea, *Ceratophyllus fasciatus*, is the most usual transmitting agent, but in addition, rat-lice and rat-fleas other than *Ceratophyllus*, are concerned occasionally in the spread of *T. lewisi* from rat to rat. *T. lewisi* has recently been shown to pass one stage of its life within the gut epithelium of *C. fasciatus*.

There are many other mammalian trypanosomes that cannot be discussed in detail here. Nor are trypanosomes restricted to mammals, for reptiles, amphibia, and fishes all are parasitized by them. The trypanosomes of fishes seem to be widely spread among the various genera, but to be present in relatively small numbers in the blood of their hosts. They are probably spread from fish to fish by various leeches. The agents of the transmission of many reptilian trypanosomes from host to host are ticks.

The amphibian trypanosomes are of interest, for one of the earliest trypanosomes ever noted was *T. rotatorium* from the frog, which was first seen by Gruby in 1843.

The method of transmission of the trypanosomes of terrestrial vertebrates is mainly by the bite of insects. Now insects, like the higher animals, have parasites peculiar to themselves, and these parasites have a superficial resemblance to trypanosomes. Unfortunately, some investigators have ignored the existence of these true insect flagellates and also that there are three definite phases to their life-history. They have jumped to the conclusion that the flagellates of insects must be developmental forms of trypanosomes, because cultures of certain trypanosomes on artificial media (and so under somewhat unnatural conditions) give forms resembling these parasites of insects. There is at present no evidence whatever that such is the case ; but, on the other hand, there is a continuous accumulation of evidence that very many flagellates occurring in insects are parasites of the insect alone, and have no connexion with the trypanosomes of vertebrates.

These flagellates, belonging to the genera *Crithidia* and *Herpetomonas*, occur in the alimentary canals of various flies and bugs, some of which insects are feeders on vertebrate blood, some on excrement of man and beast, while others feed on the juices of plants. In the case of *Crithidia* and *Herpetomonas* a definite phase of the parasite is peculiarly adapted for life outside the body of the host. This form of the parasite, which is compact and oval, is known as

the post-flagellate stage, and serves as the cross-infective agent. When it is taken into the food-canal of a new host, it reproduces the flagellate form in it. The post-flagellate stages (cysts) are capable of resisting desiccation for a considerable period, and may be distributed in the form of fine dust by the wind.

A *Crithidia* of much interest is *Crithidia pulicis*, parasitic in the human flea, *Pulex irritans*. In order to avoid errors in the investigation of this parasite, fleas were specially bred on the body of a perfectly healthy person, from whose blood no trypanosome has ever been obtained, no matter what form of examination has been employed. The fleas were confined to special areas of the body by means of flexible rubber and celluloid cages. The eggs laid by them were hatched under the same conditions, and the process repeated to the third generation of fleas, which were used for the investigation.

When the oval post-flagellates are voided by infected fleas, they are taken up by the youngest fleas with the excrement and congealed blood on which they live. These tiny fleas resemble small but very active grubs before they reach the adult stage. Adult fleas absorb the post-flagellates when piercing the skin of their human hosts to suck blood. In the fore-gut of the flea the parasites become larger, and as they form the starting-point of the life-history of the *Crithidia* in the new host, and precede the flagellate stage, they are known as the pre-flagellate forms.

The pre-flagellate form of *C. pulicis* is a somewhat

frail-looking, oval organism (Fig. 9, *A, B*), becoming more elongated as it ages. It has a large, distinct nucleus and a barlike blepharoplast. The pre-flagellate often shows a special area which will stain intensely, and so may be termed the chromatophile area. The contents of this area at first are finely granular, but little by little the granules collect and form a thread which at first is tightly

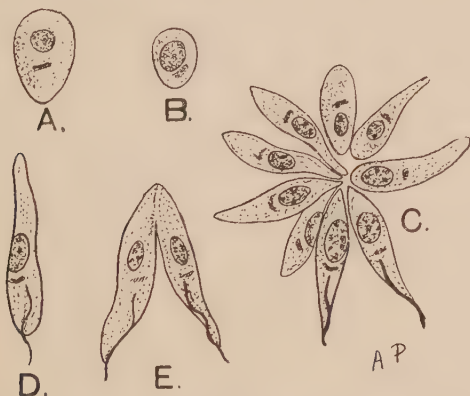


FIG. 9—CRITHIDIA PULICIS: STAGES LEADING TO THE FLAGELLATE FORM

A, B, Typical oval pre-flagellates ; *C*, rosette of elongating pre-flagellates ; *D*, single form separated from rosette ; *E*, dividing form

coiled up, but which gradually loosens its coils and reaches the surface of the body. Simultaneously the body of the pre-flagellate commences to grow, and as it elongates, the thread uncoils and presses outwards (Fig. 9, *C, D*). The limiting layer of the body, moreover, is elastic, and, under the pressure of the firm thread, moves with it, and gradually the fin-

like undulating membrane is produced at the elongated anterior end, while that part of the thread that forms the edge of the membrane continues as the free flagellum. While extension is progressing at the anterior end, the posterior end lengthens also, and becomes somewhat club-shaped. The flagellate stage is reached when the growth is complete. Division may occur in the late pre-flagellate stage (Fig. 9, *E*).

The flagellate form of *Crithidia pulicis* (Fig. 10) is a lengthened organism occurring chiefly in the mid-gut of the host, where it moves with great rapidity. The nucleus is oval, and the barlike blepharoplast is near it. The root of the flagellum is near the blepharoplast. *C. pulicis*, like other *Crithidia*, has the nucleus in juxta-position to the blepharoplast, the reverse being the case in trypanosomes, where the nucleus is anterior to the blepharoplast. This is an important difference between the two organisms. The undulating membrane is very beautiful (Fig 10, *C*). It is wide, and shows contractile threads in it. The grace of the movements of the organism cannot but be admired, for the gentle ripples and easy turns of the parasite display a remarkable balance and rhythm.

When the flagellate is full grown, it proceeds to multiply by dividing into two lengthwise. As in the trypanosome, division begins with that of the blepharoplast, and following on that the flagellum and membrane split. The nucleus becomes notched, the two clefts deepen, the parts separate, and finally the body substance becomes divided. The new forms

are aided in separating by the active lashing movements of their flagella, and organisms, looking succes-

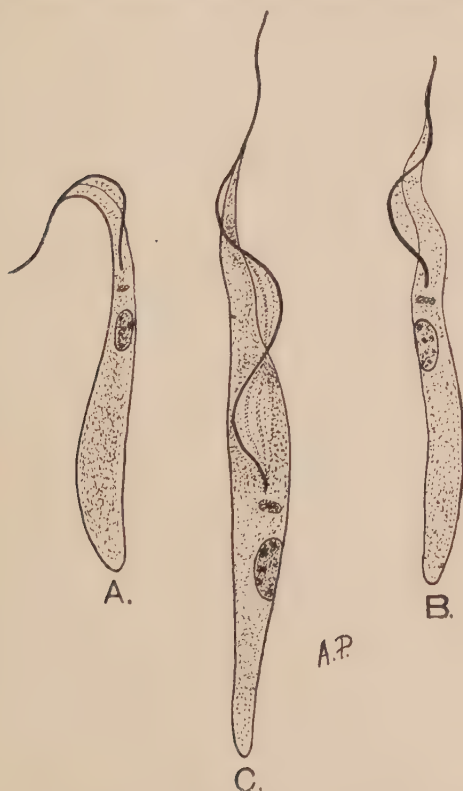


FIG. 10—CRITHIDIA PULICIS: FLAGELLATES

A, Young form; B, older form; C, full-grown form, showing well-marked membrane with myonemes

sively like an opening pair of scissors, a Y, and an enormous individual with a flagellum at each end, are encountered. If the latter be watched carefully,

a nick or constriction appears at its centre, much movement occurs, and finally the organism parts in two, the daughter individuals swimming away in different directions as soon as separation is effected. Sometimes the new individuals are equal in width, at other times marked dissimilarity occurs, and hence there is a considerable variation among the parasites encountered, due to differences both of division and of rate of growth.

Ultimately the flagellate commences to prepare for



FIG. 11—*CRITHIDIA PULICIS*: FOUR STAGES IN THE FORMATION OF POST-FLAGELLATE FORMS

life outside the body of its host, and to pass into a form adapted for transference to a new host. Gradually the *Crithidia* concentrates its body substance into a more or less oval mass. Its membrane and flagellum are absorbed, its nuclei approximate, and finally a thin, gelatinous cyst appears around the organism. This cyst rapidly hardens, forming a varnish-like coat around the organism (Fig. 11). In this form the post-flagellate stage of the *Crithidia* is expelled from the body of its first host, only to be swallowed by some small larval flea feeding on the

excrement of its elders, or by some adult flea whose proboscis pierces the skin in the neighbourhood of the fæcal deposit.

Now, while there is a temporary stage in the life-history of some trypanosomes in which there is a resemblance to a flagellate *Crithidia*, yet there is no evidence to warrant any necessary interdependence. A *Crithidia* has a distinct life-history, and the flagellate form is followed by a post-flagellate, which is a highly resistant form, well adapted for the perpetuation of the species. A "crithidial stage" of a trypanosome is but a transitory one. The life-history of a *Crithidia* is complete in itself; it is a definite entity, fixed, unalterable.

Another interesting feature may be mentioned here. A *Crithidia* is parasitic in the sheep-ked, a wingless fly known as *Melophagus ovinus*. This flagellate (*Crithidia melophagia*) has been able to penetrate to the ovaries of the ked, and live and multiply within the eggs. The result is that the young keds are born infected, and a generation of infected keds transmits the parasite to their offspring as a matter of course. The case of hereditary infection of the host with *C. melophagia* has been worked out in detail, and is of great interest. Whether the eggs of Glossinæ are infected with the trypanosomes of sleeping sickness has yet to be demonstrated, and this investigation should be a most interesting, though extremely tedious, piece of work.

Nearly allied to the genus *Crithidia*, so far as gross external form is concerned, is the genus *Herpetomonas*, and this possesses an even greater human

interest, inasmuch as certain of its members (or forms very nearly allied thereto) are responsible for the diseases known as "Kala-azar," "Oriental sore," or "Delhi boil," and "infantile splenomegaly" of the Mediterranean littoral. The parasites of Kala-azar and Delhi boil are generally placèd in a separate genus, *Leishmania*.

Here again a danger arises from generalizing on a few cases—the random sampling of the logician. Because some herpetomonads cause foul diseases, and are spread by insects, it by no means follows that all herpetomonads, parasitic in all biting insects, do the same. Nor is there the slightest evidence whatever to warrant the connexion of the genus *Herpetomonas* with that of *Trypanosoma*, because it may occur in a biting insect. Recently, a most careful investigation of lice frequenting the human body has been made, and has resulted in the discovery of a typical *Herpetomonas*. But the flagellate, known as *Herpetomonas pediculi*, is a parasite of the insect, and has no harmful effect of any sort on man.

In order to prevent the possibility of contamination from outside sources, the lice were bred and fed on the body of the investigator, and the young lice became infected by swallowing cysts in the excrement of the older ones. In the fæcal matter there are minute, oval bodies (Fig. 12, *A*), resembling those of *Crithidia*. They contain a nucleus and blepharoplast, and have a varnish-like cyst wall. These are the post-flagellates. Swallowed with fæces by other lice, the cysts become softened, the parasites grow and begin to elongate (Fig. 12, *B-D*)

thus becoming the pre-flagellate form in the new host. From a rather small chromatophile area in each, near the blepharoplast, a thread forms, extends forwards, and reaches the surface, from which it

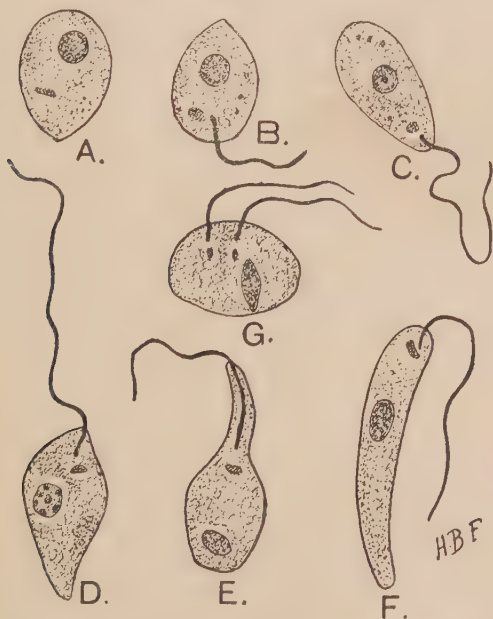


FIG. 12—HERPETOMONAS PEDICULI: PRE-FLAGELLATE TO FLAGELLATE STAGES

A-F show gradual lengthening of the body and elongation of the flagellum. G shows a pre-flagellate organism dividing

protrudes abruptly as a free flagellum (Fig. 12, B-F), often as long as the body of the parasite. In some other species of *Herpetomonas* the flagellum may even exceed the body in length. The non-flagellar end lengthens also (Fig. 12, D), and finally the long

body of the organism is complete (Fig. 12, *F*), the nucleus and blepharoplast being separated from one another by a fairly considerable interval. At this stage the organism (Fig. 13) moves about rapidly,

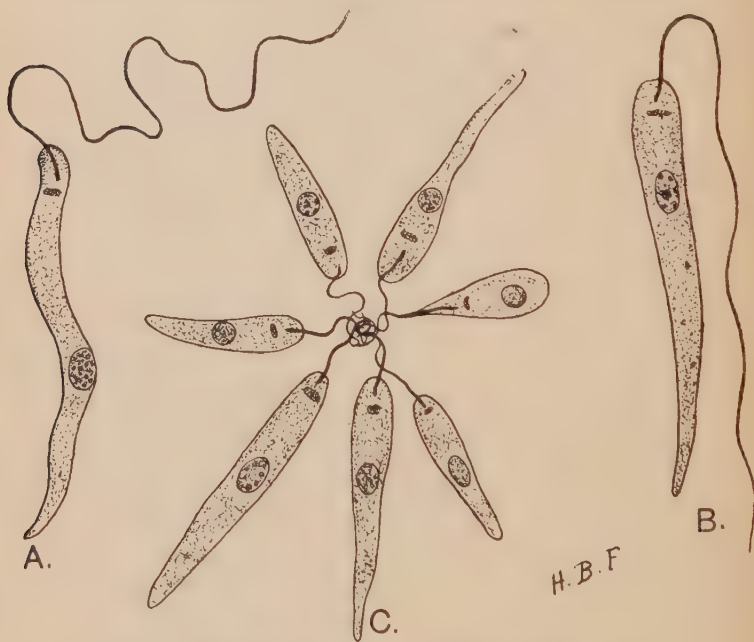


FIG. 13—*HERPETOMONAS PEDICULI*: FLAGELLATE STAGE

A, Flagellate with long flagellum; *B*, somewhat broad parasite; *C*, an aggregation rosette or cluster of flagellates of different ages and sizes, entangled by their flagella

lashing with its free flagellum, and sometimes contracting its body so that it looks like a peg-top. It moves in a jerky manner, and rolls somewhat as it swims quickly through the liquid in which it is

living. Mature flagellates sometimes become entangled together, and so form rosettes (Fig. 13, C).

Longitudinal division progresses rapidly (Fig. 14, A-D), and when this has proceeded for several generations, the organisms need a rest, and also a change of host. Each proceeds to concentrate its

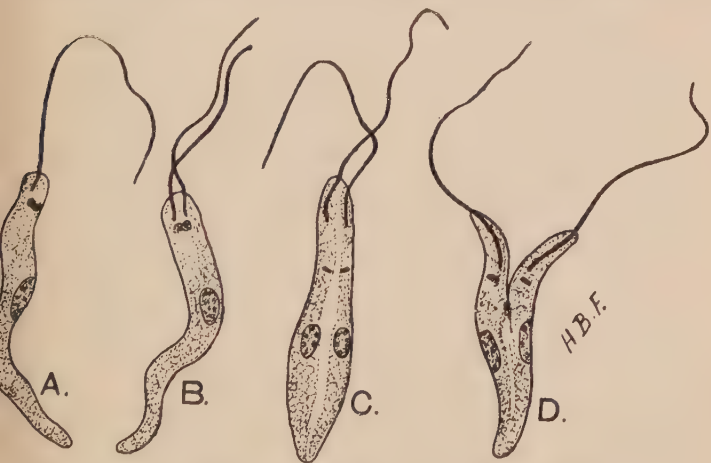


FIG. 14—HERPETOMONAS PEDICULI: DIVISION FORMS

A, Full-grown flagellate, blepharoplast dumb-bell shaped; B, commencement of division, blepharoplast constricted, flagellum divided into two; C, later stage of division, nucleus divided into two; D, commencement of separation of the daughter organisms

body substance little by little (Fig. 15, A-E), to withdraw its flagellum, and finally to form its thin but very resistant cell-wall; in fact, to reach the condition of the post-flagellate (Fig. 15, F). Voided with the dejecta of its host, it remains passive and uninjured until some new host absorbs it, when its activities recommence.

The life-history of the *Herpetomonas* of the louse has a peculiarly human interest, and it is the most recently described organism of its class. Also, although lice suck the blood of man, the *Herpetomonas* they contain has no effect, either on human

beings or on common animals, as has been shown by numerous experiments extending over three years.

The earliest known herpetomonad was the one occurring in the common house-fly, the flagellate being *Herpetomonas muscæ domesticae*.

Another flagellate, *H. culicis*, is present in the common gnat, and has the distinction of being the first *Herpetomonas*

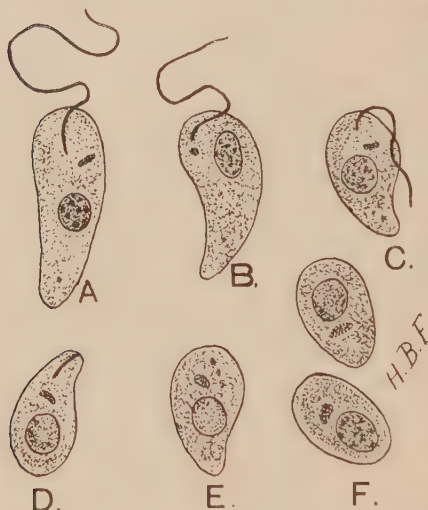


FIG. 15.—*HERPETOMONAS PEDICULI*: POST-FLAGELLATE STAGES

A-E show the progressive shortening and absorption of the flagellum and the contraction and rounding of the body; F shows encysted form (post-flagellate), surrounded by a thin, varnish-like cyst wall

whose life-cycle was worked out, this being accomplished by Captain Patton, I.M.S., who also detailed the life-history of *H. lygaei* (a form occurring in the plant-bug, *Lygaeus militaris*), and of several other

herpetomonads. The *Herpetomonas* from *Nepa cinerea*—the water scorpion—is also of great interest, since the parasite, *H. jaculum*, is gradually evolving hereditary infection of the bug. For some time the stable-fly, *Stomoxys*, has been under suspicion as a carrier of certain diseases common in India and the East, and known under various names. It has recently been shown that the *Herpetomonas* of these flies is a parasite of the insects, and is not concerned with these maladies.

The human disease known as Kala-azar, which is very prevalent in Southern India and is spreading in the Sudan, is a remarkable one due to a flagellate, a herpetomonad, which probably spends part of its life in the common bed-bug, and there develops into the flagellate form. By the bite of the bug the flagellates are believed to be transferred to the blood of the human victims. There they probably become enclosed in the colourless cells of the blood, lose their flagella, round off, and are known as the Leishman-Donovan bodies. Hence the parasite is called *Leishmania donovani*. The connexion between the Leishman-Donovan bodies and the flagellate of the bug was worked out also by Captain Patton, who ranks as one of the foremost investigators of the time so far as the flagellates of insects are concerned.

Another remarkable parasitic flagellate is the one that attacks various species of Euphorbia trees in the tropics. The first flagellate discovered in the Euphorbias was named *Leptomonas davidi* by its discoverer. The present writers possess specimens of this parasite, and consider that it is a *Herpeto-*

monas, in every way resembling *H. jaculum*, *pediculi*, *lygæi*, *culicis*, and *vespæ*, and others with which we are well acquainted. Some of the plants invaded by this parasite are said to be killed by it; on others it appears to exercise no harmful influence. It is spread from plant to plant by small plant-bugs, in whose bodies it remains apparently unchanged for a considerable time.

Certain parasitic flagellates known as *Trypanoplasma* occur in fishes, in snails, and in the flat-

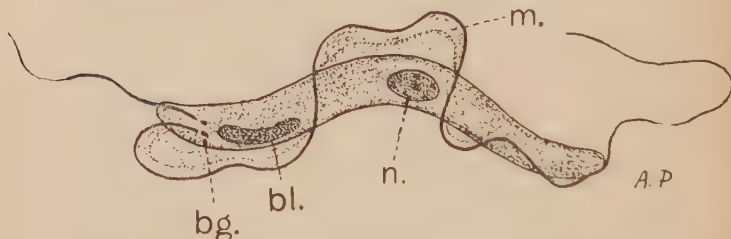


FIG. 16—*TRYPANOPLASMA DENDROCÆLI*, FROM *DENDROCÆLUM LACTEUM*: FLAGELLATE FORM

n., Nucleus; *bl.*, blepharoplast; *m.*, membrane; *bg.*, basal granules

worms known as Dendrocœls. They are remarkable flagellates (Fig. 16), bearing two flagella, one free anteriorly and the other lateral, forming the edge of the undulating membrane (Fig. 16, *m.*). The organism has an elongate body. The nucleus is relatively large (Fig. 16, *n.*), and the blepharoplast (Fig. 16, *bl.*) is most conspicuous, not only on account of its size, but also because of its curved, bowed, or kidney-like appearance. Division occurs as in *Trypanosoma*, but the splitting of both flagella occurs simultaneously, following the division of the

blepharoplast. These flagellates also form post-flagellate forms or cysts, which in the case of the trypanoplasms of *Dendrocoels* has been shown to infect young forms of the host by way of their mouths. Here, too, occurs the interesting feature of hereditary infection, the tiny *Dendrocoels* being infected when they leave the body of the mother, and the eggs of the parent sometimes seeming to consist of writhing layers of trypanoplasms around the young, developing embryos within the shell.

Another remarkable flagellate organism occurs in the body cavity of the Cœlenterates, known as Siphonophores. The flagellate, *Trypanophis*, is interesting in that a form of skeletal axis has begun to evolve, and shows as a row of bars down the body of the organism. Other flagellates with skeletal axes are known, the *Trichomonas* (Fig. 17) from the



FIG. 17—TRICHOMONAS EBERTHI, FROM THE GROUSE

intestine of the grouse and other birds, lizards, frogs, toads, and mice being perhaps the best known. In *Trichomonas* the supporting bars are fused to form a rod. The organism also possesses an undulating membrane and four flagella, one of which forms an edge to the membrane. A *Trichomonas* is sometimes found in the intestine of man, and may be associated with diarrhœic conditions.

When certain of the more important Flagellates (from the economic point of view) are considered, there would appear to be a close connexion between the three genera, *Herpetomonas*, *Crithidia*, and *Trypanosoma*. The *Herpetomonas* is certainly the simplest form. It possesses no undulating membrane, but has a long free flagellum arising near the anterior blepharoplast, and a central nucleus. Somewhat higher in the scale of organization are the various *Crithidia*, which resemble *Herpetomonas* in the general outline of their structure and life-history, but possess a more complex structure, in that a relatively small undulating membrane is present. In *Trypanosoma* the body differentiation is even higher, for the undulating membrane is large, and extends almost the whole length of the body, originating as it does near the posterior blepharoplast.

Interesting speculations also have centred around the problem as to whether the insects or the vertebrate were the primitive host of the trypanosome. The line of speculation that seems to have most in its favour appears to be as follows: The parasitism in man or other warm-blooded vertebrate has been evolved from parasitism in an insect. The parasite may have begun its career originally as a

free-living form, quite independent of any animal. Certain of its members, having been ingested by some insect, say, become habituated to living in the alimentary tract of the new host. At first the host, perhaps, was caused inconvenience by its invader, but later became accustomed to its presence and immune to any evil effect. From the main alimentary canal the flagellate reached other organs of the body of the host—at any rate, in some cases.

A further stage in the scale may have been the result of the acquiring of the sanguivorous habit by the insect. The latter, having in turn become parasitic externally on higher animals, pierced the flesh of a vertebrate, and in so doing injected a small number of its contained parasites into the wound. Many probably died quickly in the blood-stream, but some, being of a hardier nature than their fellows, began to divide, to develop along somewhat different lines from their ancestors, and finally to become the pathogenic agents of such maladies as the tsetse-fly disease, nagana, or even sleeping sickness.

Such is one speculative view, interesting enough in itself, and being an hypothesis for which more can be said than for most. For in this case there are a certain number of facts on which the above speculation is based. Recently it has been shown that *H. stenocephala*, from the gut of the dog-flea, and *Cryptosporidium parvum*, from a mosquito, can be successfully inoculated into mice. Such experiments furnish examples of leishmaniasis (see Chapter X.) in the making. Further researches on these lines will be awaited with interest.

CHAPTER IV

THE SPIROCHÆTES: BORDER-LINE ORGANISMS BETWEEN PLANTS AND ANIMALS

AMONG some of the most interesting lowly organisms are the spirochætes, which, like some flagellates, either live freely in water, or inhabit the digestive tract of many animals, or are found in their blood. When they adopt the parasitic habit in the blood, they can become deadly to man and other vertebrates. The spirochætes have already been noted (Chapter I., p. 10) as presenting a good example of gradual adaptation to parasitism, and now more may be added as to their build, life-history, and importance.

The spirochætes are a group of organisms with a history. Lying as they do on the border line between animals and plants, they have been the centre around which much controversy has raged. It will be the endeavour of the present writers (who have worked personally on many members of the group) to give an account of these organisms that shall be as non-controversial as possible, and which will consist of facts and not the speculations so fashionable nowadays.

In 1833 Ehrenberg found the type *Spirochæta* in muddy pond-water, and described it very briefly indeed. From that time onwards the *Spirochæta plicatilis* of Ehrenberg seems to have been almost unobserved; and, even at the present time, there is little evidence that any one of the spirochæte-like organisms of pond-water, recently described as *S. plicatilis*, is the same as the spirally moving organism seen and depicted by Ehrenberg.

However, workers after Ehrenberg identified the genus *Spirochæta* with certain organisms found in sea-water (*S. gigantea*), and in a blind branch of the gut of the oyster that contains a jelly-like substance, the crystalline style. In 1882, Certes, working on the parasites and commensals of the oyster, wrote a note on the organism, though he called it a trypanosome, while in 1883 Moebius published that he had observed the oyster parasite in 1869. A gap occurred till 1905, when Schaudinn extended the definition of the spirochætes, for he stated that an undulating membrane should be present along the corkscrew-like body.

Meanwhile, workers in Tropical Africa had recorded spirochætes from the blood of man and mammals, and the study was pushed forward, but beyond increasing the number of species known, little in the way of structural detail was observed until 1906. In that year a paper appeared by Perrin on the parasite of the oyster, which he termed *Trypanosoma balbianii*, despite the fact that in practically no structural detail did it resemble the trypanosomes, then a relatively well-known

genus of organisms. Concurrently, one of us had been studying not only the spirochæte of oysters, but also a new species of spirochæte discovered by us in the British fresh-water mussel, *Anodonta cygnea*, and the results of this work were published in 1907-1908, with an extension in 1909. Other spirochætes from sea-mussels, Tapes, Solen, Sphærium, sheep-keds, bees, wasps, grouse, fowls, monkeys, and man and other animals, have since been recorded and described by us. Naturally the greatest amount of detail can be obtained from the structure of a relatively large spirochæte, such as that from the oyster, and much valuable information can be obtained from it. Nevertheless the same structures on a far smaller scale—and hence with less definiteness—can be observed in most of the smaller spirochætes, such as those inhabiting the blood of mammals and birds.

The study of spirochætes is well commenced, then, with those found in the crystalline style and digestive tract of the edible “shellfish,” oysters, sea and fresh-water mussels, and Tapes, the latter being in common use for food on the coasts of the Mediterranean.

The body of any spirochæte is a long, slender structure (Fig. 18) which twists spirally on itself, and is capable of rapid extension and contraction. The number of coils is not fixed. The sinuous body extends outwards as a spirally wound protrusion forming a “fin” or flange called a membrane (Fig. 18, c), the winding being much like that of the thread of a screw. This membrane serves to

impart steadiness to the motion. It is traversed by contractile elements known as myonemes (Fig. 18, *d*), and myonemes may also be present in the body itself. They are most important, since it is by the action of the myonemes that the movement of the organism is brought about. Bordering the membrane is a noticeable, thickened myoneme forming a chromatic margin. The membrane extends the whole length of the body, but the chromatic border is not continued as a free flagellum. At each end of the organism is a small, roundish, basal granule (Fig. 18, *a*) or small polar cap. Extending through the body of the organism is a series of barlike chromatin masses (Fig. 18, *b*), which represent the nucleus. As the nuclear material is thus scattered, the nucleus is said to be diffuse. The appearance of this nucleus varies in life, displaying slightly different appearances according to the phase through which the spirochæte is passing at the time when examined. The appearances described hereafter have been observed by us repeatedly in living spirochætes from molluscs,

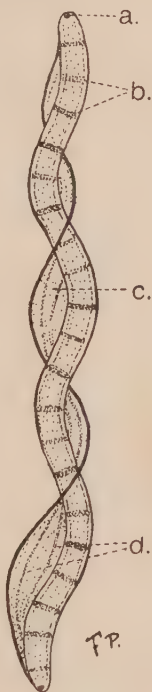


FIG. 18 — SPIROCHÆTA
BALBIANII, FROM THE
OYSTER

a, Basal granule; *b*, bars of chromatin; *c*, membrane; *d*, myonemes in membrane. Two slight myonemes are also present on the body

and several methods of examination have been adopted, with invariably the same results.

The nucleus of a spirochæte is of a complicated nature. First, the body of the organism is traversed by a helix or spirally coiled thread of feebly staining substance. Arranged on this snail-shell-like thread are a number of chromatin bars, which may appear to be of different thicknesses owing to the fact that they are situated at different depths. These bars do not extend quite across the organism, which is thus really unsegmented, though at first sight it may present a "chambered" appearance. During periods of great activity of the spirochæte—for example, division—the nucleus undergoes much change, which will be described later.

There are two methods of multiplication by simple division of spirochætes, and both can be observed in life. The organisms divide both longitudinally and transversely, the first method resulting in long, narrow forms, the second in shorter, thick ones. Preceding longitudinal division, there are nuclear changes, best seen in large spirochætes such as *Spirochæta balbianii* of the oyster and Tapes, and *S. anodontæ*. The bars of chromatin begin to concentrate their substance into two masses, one at either end. The two portions gradually draw apart, and two rows of dots are seen instead of bars. Meanwhile the basal granule at the origin of the membrane divides into two, and following that, the membrane splits longitudinally, so that the spirochæte now shows two membranes and two basal granules on one body, while the chromatin extends

throughout as a duplicated row of dots with the unstaining portions as tags to them. The body protoplasm now concentrates around the dots, and a relatively clear, central area is produced. A split in the body begins at one end, and the two limbs so formed begin to move rapidly. Their vigorous lashing extends the slit, and finally the two newly formed organisms lie in a straight line, and by moving in opposite directions effect the final separation. As the halves of the parent spirochæte separate, so the tags on which the bars of nuclear material rest join up, forming a new zigzag skein, along which the granules gradually spread out to form new bars. The chromatin during the intermediate portion of the division period shows a series of well-marked spiral lines. We would again emphasize that all these features can be seen in life by using the paraboloid condenser, and that the division has been followed from beginning to end.

Transverse division also occurs. In this case a spirochæte begins to elongate, and as it does so, a series of ripples or waves pass along the body of the organism from each end, a neutral zone being thus created where the two waves meet. Return waves of less intensity then pass from the central node outwards to the ends, die out, and are succeeded by a new series, which neutralize one another at the same point as previously. The number of waves increases in frequency, and the time of each wave is correspondingly shorter. Great strain is thus brought to bear on the spot referred to as the central node, and a perceptible thinning of the organism occurs

here. Also the protoplasm tends to pass from this region of the organism to a great extent. When the strain due to the succession of wave-pulls becomes too great, the spirochæte parts in two, and the elastic outer layer of the body—the periplast—

closes over the separated ends. The two daughter organisms thus produced usually swim away in opposite directions.

There is an enormous variation in the size and appearance of the spirochætes found in any one mollusc, but practically all the differences can be explained by reference to the modes of division, followed by subsequent growth. When longitudinal division occurs rapidly—as it often does—then a multiplicity of forms of all grades of thickness is found (Fig. 19). When, on the other hand, transverse division has been frequent, the spirochætes present greater variations so far as length is concerned.



FIG. 19—MORPHOLOGICAL VARIATION IN THE SPIROCHÆTE FROM *TAPES AUREUS*

Longitudinal division, followed so rapidly by transverse division that the products of the first fission had not effected their final separation, has been observed in certain of the spirochætes of molluscs. On the other hand, this last phenomenon has not been seen in the blood-spirochætes, but there appears

to be a periodicity in the direction of division exhibited by them. Longitudinal division is the commoner method of multiplication when the infection is scanty, and this is succeeded by transverse division when the parasites are very numerous in the blood. Naturally, there is a bridging period when the two forms of division go on side by side, but it has been shown to be a somewhat short one.

The movements of spirochætes are of extraordinary interest, not only for their own sake, but also on account of the numerous inaccuracies that have arisen owing to normal movements of growing individuals being mistaken for stages in division. Again, some persons have denied the existence of longitudinal division because they themselves have not observed it. Needless to say, their misfortune does not invalidate the fact of undoubted longitudinal division. It merely emphasizes the need of more careful and prolonged observation, together with a search for the probable periodicity.

Movements in spirochætes depend partly on the body, but chiefly on the myonemes of the membrane. Their forward movements have been carefully analysed, and two components occur. The first movement is a wave-like (vibratory) motion of bending or flexion of the body which is mainly for progress in a forward direction. This movement is accompanied by a second, that of a spiral or corkscrew-like motion of the body as a whole, due to the spiral winding of the membrane.

Spirochætes can reverse their direction of progress with the greatest of ease. They pass and repass the

same spot repeatedly. Their course is usually a straight one. When movement is very rapid, the membrane is drawn nearer to the body to lessen the resistance to the medium in which the organism is placed. Slow-moving spirochætes show wider—that is, relaxed—membranes.

Simple looping movements are common. The parasites bend on themselves, form loops like **U**, and each arm alternately is raised and lowered. A variation of this is seen when the two arms of the **U** intertwine, and the two ends only are free. This phenomenon has been seen in thousands of specimens, but the results of our own observations have been that the spirochætes finally disentangled themselves and swam away. Other observers say that transverse division occurs at the bend, and consider that this peculiar bending has been mistaken for longitudinal division. This is not so. In longitudinal division one body is seen at one period, and there is the succession of nuclear changes, the doubling of the membrane, and until the final separation occurs, one thick parental body with two thinner daughter ones originating from it. Such a body arrangement is never seen in entanglement phenomena.

Again, spirochætes use a sort of boring movement, and spirally bore their way upwards through the medium surrounding them. Their appearance as they advance obliquely towards the surface is that of an animated Catherine wheel rotating violently on itself.

Watchspring-like coilings and uncoilings occur,

and sometimes the spirochæte seems to roll itself up into a ball. Further, the ball may be central or terminal, or in any position between the two. Usually, if watched long enough, the ball unrolls again and the organism swims away unchanged. If stained preparations only be examined, the conclusion is that these balls are veritable cysts, and that the spirochætes have produced a resting form. Such a resting stage is, however, still problematic in the case of nearly all spirochætes.

Not only have the modes of division and movements of spirochætes been studied in the larger spirochætes of Lamellibranchs, but we have also minutely examined the smaller ones parasitic in the blood of mammals and birds and in the alimentary tracts of certain insects. There is a remarkable similarity between the structure and movements of these blood-dwellers and of those spirochætes inhabiting the crystalline styles of molluscs. Further, the life-cycles of all the spirochætes fully investigated are on the same lines. It would, perhaps, be as well to complete the life-cycle of the molluscan spirochæte, for this cycle usually needs one host for its accomplishment, whereas the blood-spirochæte often undergoes one stage of its development in a second host.

Spirochæta balbianii of oysters, Tapes, and other molluscs, *S. anodontæ*, *S. mityli*, and also *S. solenis*, have been under observation by us for some years. During this time, small, ovoid bodies ("spores") of the same diameter as spirochætes have been found from time to time, and also empty sheaths in both the crystalline style, the alimentary tract, the in-

testinal contents, and the water in which the molluscs were kept. The significance of these forms was considered, but until the actual formation of spirochætes from them and of them from spirochætes had been repeatedly seen, and confusion with extraneous

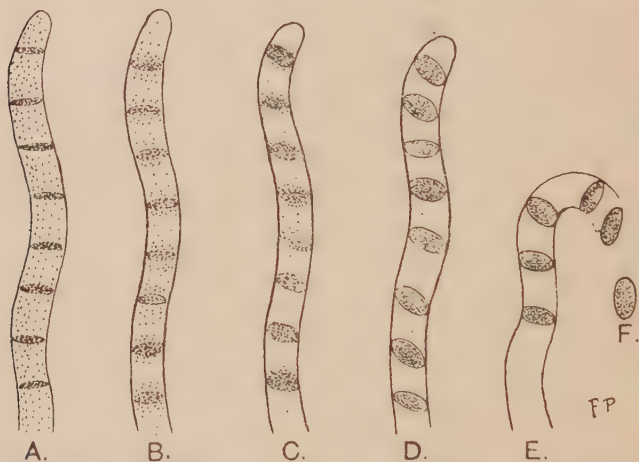


FIG. 20 — TO SHOW THE FORMATION OF OVOID OR COCCOID BODIES (AS IN *SPIROCHÆTA BALBIANII*) WITHIN PART OF A SPIROCHÆTE. ALL DETAILS OF MEMBRANE, ETC., OMITTED FOR THE SAKE OF CLEARNESS

A, Normal spirochæte, with chromatin bars and tenuous cytoplasm; *B*, concentration of protoplasm around the bars commencing; *C*, ovoid bodies differentiating; *D*, fully formed ovoid bodies within the periplast; *E*, periplast ruptured and degenerating, ovoid or coccoid bodies (*F*) escaping

bodies absolutely excluded, the results were not published. The spirochæte that is about to form "spores" by multiple transverse fission shows no difference at first from an ordinary form. Its chromatin is disposed in bars, and the cytoplasm is distributed. But soon the protoplasmic contents of

the spirochæte begin to concentrate around the chromatin bars (Fig. 20, *A, B*), and thus a number of segments are formed within the spirochæte, whose periplast acts as a sheath. The further concentration of the cytoplasm (Fig. 20, *C, D*), gives rise to a number of small oval or rounded bodies, sometimes termed "spores" or "granules" (Fig. 20, *D*). Sometimes these small spores lie transverse to the long axis of the spirochæte; at other times they may be slightly curved and lie obliquely. The result resembles a series of biconvex or rounded tabloids within a thin skin. Ultimately, the periplast ruptures at one end (Fig. 20, *E*), and the small bodies, which for convenience we term "spores," issue into the food-canal. These spores or coccoid bodies (Fig. 20, *F*) are probably able to withstand conditions unfavourable to the spirochætiform stage of the parasite. It has been suggested that coccoid bodies or spores are degeneration products. Degenerating spirochætes have a very different appearance from those forming spores, and, further, degenerating members do not reproduce a new and vigorous race of spirochætes as do the spores. The spore develops into a spirochæte by the same series of changes as does the corresponding form of a blood-spirochæte, and will be described in detail there.

The function of the spores is, obviously, to serve as a means of transference to a new host. But among molluscan spirochætes, cross-infection with mature spirochætes by the direct agency of water has been shown. Apparently clean *Tapes aureus*, placed in water containing oysters known to be

infected with *Spirochæta balbianii*, have themselves become infected in the course of a few days, as have also clean Tapes placed with infected ones. Similar experiments, using *Ostrea edulis*, *Pecten jacobæus*, and *Tapes aureus*, had similar results, showing that the spirochætes of these three hosts are, in the end, one and the same organism. *Sphærium corneum* has been cross-infected from *Anodonta cygnea*, though with greater difficulty. Water in the aquaria in which infected molluscs had been kept usually yielded spirochætes identical in every particular with those in their mantle cavities or intestinal tracts. No intermediate animal host is necessary for the transference of molluscan spirochætes from host to host, that function being accomplished by the surrounding medium.

Both oysters and mussels harbour certain commensals, but so far none of these organisms have been definitely proved to act as agents in transferring spirochætes from host to host. It is true that one of us (1911) has found spores or bodies strongly resembling them in the small *Atax bonzi* which frequent the mantle cavity of *Anodonta cygnea*, and that some of these bodies become rodlike; but we maintain the attitude adopted two years ago, that "as the complete metamorphosis of them into spirochætes has not been observed, it is well for the present to consider them as being under suspicion of being evolutionary stages of *Spirochæta anodontæ*, though they might be separate bodies."

Turning our attention now to the blood-inhabiting spirochætes, it will be found that spore formation,

which was the less usual alternative method for cross-infection in the spirochætes of Lamellibranchs, has become the usual course for the spirochætes of the blood. Commonly the formation of spores is accomplished in an invertebrate, often a tick, but spores also form occasionally in the blood-spirochætes while still within their vertebrate hosts. The process of formation of spores is, in every detail, like that of the molluscan spirochætes, but on the rupture of the periplast the minute spores issue direct into the blood-stream, and there undergo further development. We have traced the development of spores in *S. duttoni*, *S. recurrentis*, and *S. gallinarum*. The multiple transverse fission does not appear to be an essential phase in the life-history of the spirochæte when within its vertebrate host, but in our opinion is really an anticipation of what occurs in the invertebrate carrier.

The history of the spirochæte granules in the vertebrate host is of some interest. In 1906 Prowazek recorded the intracorpuseular stages of *S. gallinarum*, the spirochæte of fowls' blood. Breinl (1907) had observed *S. duttoni* forming granules in the spleen. Balfour (1908) stated that the ovoid bodies or granules formed by *S. gallinarum* occurred within the red corpuscles of the fowls' blood. Recently one of us (Fantham, 1911) observed in some smears of human blood from a patient who had apparently recovered from African tick fever some very interesting forms of *S. duttoni* within the red cells. The spirochætes showed spiral bodies with terminal swellings, somewhat resembling sper-

matozoa. They also had a similar appearance to some forms of *S. nicolleti* as figured by Blanc, occurring in the fluids of the body cavity of the tick, *Argas persicus*, that carries spirochætes from fowl to fowl.

With regard to the stages of spirochætes in certain of their invertebrate hosts, a considerable amount of information has accumulated of recent years. In 1905, Dutton and Todd showed that the tick, *Ornithodoros moubata*, was the carrier of *S. duttoni*, the cause of human African tick fever, and they further demonstrated that the spirochæte was capable of passing through the gut walls of the ticks and reaching their body cavities. Also these workers were the pioneers in investigating the phenomenon of hereditary infection. They proved that the tiny nymphs of *O. moubata*, so small as to be hardly recognizable and resembling tiny, spiky particles of sawdust, were more to be feared than their parents, for while both might be equally infected, the minuteness of the nymphs rendered them far less easy of detection. Markham Carter (1907) continued the progress in knowledge, showing that the spirochætes multiplied by longitudinal division and broke up into granules. Balfour, working at Khartoum with *Argas persicus*, the carrier of fowl spirochætes, showed the granular phase of *S. gallinarum* within the tick.

The *exact* method of transmission of spirochætes by ticks was first set forth by Leishman in 1908 for *S. duttoni*. Prior to this date, it had been thought that the salivary fluid of the tick was the source of infection. In the early part of 1909 one of us had

the opportunity of confirming Leishman's work. By experiment it was proved that infected salivary fluid was not the common means of inoculating the virus, but that other body excretions of *O. moubata* were concerned. Two other excretions of *O. moubata* are well known. The tick possesses important nitrogenous waste-excreting organs (Malpighian tubules), which discharge their fluid into the gut. A clear fluid from glands near the junction of the legs and body—the coxal glands—is also excreted. Now, by detailed experiments, it has been shown that the Malpighian secretion is the main infective agent. When a tick sucks blood, a clean-cut wound is made by its jaws. Blood passes steadily into the body of the tick, and presently the clear coxal fluid is ejected from the body and forms a thin layer on the under-surface of the tick. This fluid is non-infective. But towards the end of the feeding the denser Malpighian fluid is voided, becomes diluted by the coxal fluid, and flowing over the under-surface of the body of the tick, and into the wound made by the jaws, it transmits the parasite to the new host.

The changes undergone by the spirochæte in the tick may now be described. When the organisms are swallowed by the tick, they pass into the gut, where some of them are digested, while others resist digestion for a considerable time. They may remain as spirochætes in the alimentary canal for periods which vary in their duration according to the temperature at which the tick is kept. Some of the spirochætes pass through the wall of the gut and reach the fluid in the body cavity, where they often

attach themselves to the corpuscles floating in the fluid, or may even penetrate them and live within them. Whether they remain in the gut or not, the spirochætes sooner or later begin to divide to produce small spores exactly in the same way that has been described for those present in the blood of the vertebrate. The concentration of the protoplasm around the chromatin bars and the concentration of the outer portions to form the coats of the spores, occur, perhaps, at a somewhat quicker rate than they do in the blood, while the periplast sheaths are more rapidly disintegrated. But the procedure is not really varied in any way; the rate of spore formation alone is affected.

Mention has been made of the fact that the spirochætes are capable of leaving the gut and of entering the body fluid. Some of the spirochætes penetrate the hæmocœlic corpuscles, and there divide rapidly to produce ovoid bodies or spores. Other spirochætes divide while still free in the hæmocœlic fluid, and the small, ovoid bodies produced are carried to the various organs. Some find their way from the gut into the Malpighian tubules and form granules. These are voided with the excretion, and thus may enter any host bitten by the tick.

The Malpighian secretion is not the only means by which infection is spread. The full-grown spirochætes and the ovoid, coccoid bodies alike are carried in the hæmocœlic fluid to the ovaries, and penetrate the ova. The development of the spirochætes in the egg was first demonstrated by Leishman, and was confirmed and amplified by Balfour, Fantham,

Hindle, and others. It has been shown that the small coccoid bodies float at first in the vitellus. The first organs that develop within the egg take the form of two long narrow structures which are the primitive Malpighian tubules. Each at first consists of only a few cells, but into each of these the spirochætes penetrate. The ovoid bodies also concentrate in the cells and form small clusters. The large spirochætes, once they have penetrated, rapidly divide and produce spores. Hence the Malpighian tubules soon become crowded with granules collected in clusters. The same procedure is followed, whether the eggs be those of *Ornithodoros moubata*, the carrier of *Spirochæta duttoni*, or *Argas persicus*, that transmits the parasite of fowl spirochætosis. The results of microscopical examinations of infected ticks' eggs may now be shortly summarized :

The egg, when freshly laid, shows as a rule no spirochætes. It is only in extremely thin smears of the egg, and then with difficulty, that the tiny ovoid bodies can be detected. When the eggs have been incubated from three to five days, the Malpighian tubes of the young embryo have developed. Some of the yolk also has been absorbed, and consequently it is much easier to detect the ovoid bodies which have concentrated in groups in the developing Malpighian tubes. Some of the spores also have begun to lengthen.

Six to seven days of incubation results in more organs of the tick having formed. The ovoid bodies have lengthened in many cases, and some of them have ruptured the cells in which they were lodged,

and have escaped as bacillary forms into the lumen of each Malpighian tubule. After the seventh day the organs of the tick develop very rapidly, and there is much difficulty in observing the change of the bacillary forms into the typical spirochætes. But two methods seem possible. In the first case fusion of two or more bacillary forms may occur. In the second case growth in thickness and simple elongation of the bacillary form produces the spirochæte, and all the observations made seem to show that this is by far the commoner method.

The freshly hatched (and infective) nymphs of either *Argas persicus* or *Ornithodoros moubata* are very small indeed. If they are kept at a temperature of about 35° C. for some five or six days and then dissected, it is found that within their intestines there are usually many ovoid bodies, some bacillary forms and a very few fully developed spirochætes. Experiments with such nymphs have shown that they are very infective, and that animals bitten by them, provided that the Malpighian fluid enters the wounds, rapidly develop spirochætes in their blood.

Another interesting fact is that the ticks born of infected parents grow up and become mature, and are capable of transmitting the spirochætes to their eggs, so that the third generation of ticks may be born infected. Hence there is the constant danger of repeated hereditary infection to be considered in any preventive measures relating to tick fevers.

While the life-cycle of *Spirochæta duttoni*, the parasite of African tick fever, is now well established, that of *S. recurrentis*, the agent of European and

North African relapsing fevers, has not been fully worked out. The mode of transmission is very different from that of *S. duttoni*, and it is possible that there will be some differences in the life-cycle when that is completely known. The long labour of Nicolle, Blaizot, and Conseil on the mode of transmission of *S. recurrentis* and its North African varieties has resulted in establishing the body louse as the means whereby the fever is spread. Watching the sequence of events in Nature, it was found that the victims of spirochætosis were often not so situated as to be attacked by bugs or ticks, but that many of them harboured lice on their persons or in their clothing. Lice, then, seemed the likely transmitters, and it was assumed at first that the disease was spread by their bites.

One of the above workers then fed lice known to be infected with spirochætes on himself, using over five thousand in one experiment. No infection followed, though many thousands of bites were received. The experiment was repeated, but still no infection ensued. The spirochætes, then, were not inoculated by the bite of the louse, and another method was sought. Again, what happened in Nature? The irritation of the louse-bite caused the victim to scratch, and by so doing, one or more lice were crushed on to the skin. This, then, seemed a channel of infection. One of the above workers scratched his own skin, and put the contents of two lice known to contain spirochætes on the slight abrasion thus produced. Infection followed in about five days. The experiment was repeated both on

the human subject and on animals such as monkeys and guinea-pigs, with exactly the same results. A second type of experiment was made by putting lice contents on the conjunctiva—the membrane lining the eyelids. Again infection resulted. This method of infection is quite probable in Africa, where, owing to the attacks of flies, etc., and the ever-present dust, the hand, contaminated with the body contents of an infected louse, might easily be used to rub or touch the eye.

A further point of interest worked out by these French investigators in Tunis was that not only did the lice retain the infection practically throughout their lives, but the spirochætes passed into their eggs. These eggs, if crushed, were infective to man, while the larvæ issuing from the eggs of infected parents were also infected and capable of transmitting the spirochætes to man. Here, as well as with *Ornithodoros moubata*, hereditary infection prevails.

A few remarks may be made with regard to the nomenclature of the spirochætes. Recently it has been suggested by certain German workers that the spirochætes of Lamellibranchs should be separated from the blood-inhabiting group, and should be termed *Cristispira*, a name based on a trivial quibble with regard to the use of the term "membrane." Reference is also made to recent work on an organism which is supposed to be the same as that which Ehrenberg described as the type species, *Spirochæta plicatilis*. Now, Ehrenberg published in 1833, and naturally was unable to give a full account

of the internal structure of his organism, while his pictures also gave no detail. *S. plicatilis* had been lost sight of for many years, but in 1910, an account of the organism was given by Fräulein Zuelzer and another by Professor Doflein, while the work of Schaudinn (1905) contained yet another account of *S. plicatilis*. But the accounts thus given by three recent writers are so diverse from one another, and their illustrations also differ so considerably, that one is forced to the conclusion that the workers concerned must surely have been dealing with different organisms, while there is a possibility that neither of them was really examining *S. plicatilis*. Consequently any classification based on resemblances with, or differences from, *S. plicatilis* are necessarily on an insecure foundation.

Again, the founding of *Cristispira* based on an incomplete knowledge of the organisms was very unfortunate, for since the name was coined, a large amount of evidence has accumulated which shows plainly that the spirochætes found in pond-water, the spirochætes found in the gut or crystalline style of molluscs, the spirochætes of insects, and the spirochætes inhabiting the blood of birds and of mammals have the same life-cycle. Each form produces ovoid bodies (spores), which are able to elongate and grow into the typical spirochætes, the methods of multiplication by fission into two are found in each case, while the internal structure is on the same plan in each of the organisms concerned. With the further details of the life-history and the elucidation of the common plan running through all,

the splitting of the group and the renaming of the molluscan forms as *Cristispira* is not only unnecessary but is misleading.

The parasite of syphilis was first regarded as a spirochæte, but later was renamed *Treponema pallidum*, because the coils of the body were said to be fixed. Balfour recently has shown that *Treponema* is a "granule shedder"—i.e., it produces ovoid bodies just as spirochætes do. In this case it seems very probable that it is only the minuteness of the organism that prevents full knowledge of its internal structure, and that for the same reason its coils appear fixed. There are undoubted affinities between all the organisms mentioned, and it seems far better to keep the older nomenclature and not to attempt re-classification until the life-history of each form has been fully elucidated. Building on an insecure foundation has the disadvantage of causing endless patching and emendation later, and the old saying, "More haste, less speed," is as applicable in protozoology as elsewhere.

Much debate has also arisen as to the systematic position of the spirochætes. The medical world and many of the leading zoologists regard them as a new class of the protozoa, the Spirochætacea, while others consider them bacteria. It has been said recently that the formation of ovoid bodies or spores is evidence of their bacterial affinity, but no one regards coccidia as bacteria, yet they also produce spores. However, the term spore is difficult to define. The body structure of a Spirochæte is probably more complicated than that of bacteria,

though resembling the latter, and its reproduction also differs. The chemical nature of the periplast is not that of the bacteria. Lastly, the mode of transmission by the agency of invertebrates is typical of protozoal parasites, as the method of infection resembling that of, say, a human subject with *S. duttoni* by *Ornithodoros moubata*, is apparently unknown for bacterial diseases. The hereditary infection of successive generations is also considered to be an argument in favour of the protozoal nature of the spirochætes. Thus the spirochætes exhibit affinities both with protozoa and with bacteria. They are, in fact, intermediate to these two groups in many respects, and are well termed border-line organisms between animals and plants. In conclusion, we think that the balance of evidence is somewhat in favour of the inclusion of the spirochætes among the protozoa and of the adoption of the new class, the Spirochætacea, which was first set forth in 1907.

CHAPTER V

MALARIA AND MOSQUITOES

ONE of the romances of science is that of the discovery of mosquito-borne malaria. India and Africa more particularly have suffered from the malarial scourge, and the commercial progress of the world has been held back for many years because the ubiquitous mosquitoes, small and insignificant as they are, proved too great an enemy, and stopped the cutting of the Panama Canal. Not that the originators of the canal scheme understood that their work was to be brought to nought by the agency of small insects! Far from it. They ascribed the succession of deaths among their employees to the mists that rose in the evening, to the odours arising from the mangrove-fringed pools and stream-sides, to the attacks of the chigoes and other irritating objects, to the heat of the sun; in fact, to almost any cause other than the real one—the germs carried by the bites of the mosquitoes.

Nor were the victims of the mosquitoes along the shores of the “great ditch” between the Atlantic and Pacific the only ones. True, they learned by bitter experience to try to live in the higher regions

away from the waterside; but in this respect they were little better than the Elizabethan sailors, who considered that "miasmas" and "low fevers" only attacked those living in lowlands or near streams, and that to "live high" was the sure course to safety in dwelling in tropical lands, whether the Americas, the West Coast of Africa, or India, were their destination.

Though they were not possessed of the scientific advantages of modern times, these Elizabethan sailors were shrewd observers, and there was much truth in their ideas that living away from streams and marshes largely destroyed the liability to attacks of "ague" and "low fever." From the modern point of view, let us examine their conclusions.

Imagine a swamp, such as those investing the mouth of the Amazon to-day, or that was present in the Panama Canal zone ten years ago, or that exists in many an Indian district at the present time. A pool of water, warmed constantly by the hot sun in daytime and with little cooling at night, is edged with soft black mud, rich with the dead and decaying remains of countless generations of vegetation which surrounds its margin. Here and there a mangrove thicket reaches the water, and the roots, forced under these circumstances to reach the air, stand up as aerating ridges above the fœtid mud. A low "humming" or "buzzing" fills the air, and soon the observer sees numbers of gauzy-winged insects flying near the edge of the pool, and finally remaining, almost motionless, on the surface of the water. These insects, if captured, are found to be mosquitoes

and gnats, practically all females, and they have come to the water to lay their eggs. One may be the tiny, grey-striped "Scot's Grey gnat"—the *Stegomyia*—responsible for yellow fever. This ghostlike insect, though almost ubiquitous, prefers smaller quantities of water. Far more obvious are other gnats (*Culicines*) and the true mosquitoes (*Anophelines*), and woe betide bird or man respectively that happens to be in the neighbourhood when these insects wish to lay their eggs. For the egg-laying demands much energy, and the source of energy for the gnat is the blood of the bird, and a meal of human blood is the best aid to the female mosquito in discharging her creative function, and in providing the strength for placing her many eggs in the medium most suitable for their development.

Examine the surface of the pool after the winged insects have gone. Here and there minute oval spots among the vegetation mark the eggs of the *Culex*, often called the "house mosquito," or "house gnat." These brownish eggs are bound together into a raft and float on the water with their more pointed ends upwards. In contrast, scattered masses of somewhat boat-shaped *Anopheline* eggs, lying irregularly on the surface, can be found with the aid of a lens. Much the same size as the eggs of the *Culex*, they do not form rafts, but form patterns (stars, triangles, rows) on the surface, sometimes near water-weed, if such be available.

Watch the water the next day or so, and instead of passively floating rafts or eggs, numbers of minute wriggling forms are seen. These are the freshly

hatched larvæ. Almost invisible to the naked eye, they are readily detected by the shimmering of the water caused by their activity, and they rapidly increase in size. Soon the larvæ can be seen creeping near the surface of the water. They finally become $\frac{1}{3}$ to $\frac{1}{2}$ inch long, and swim about actively in search of food. This they obtain from the organic material in the water as well as from minute algæ and bacteria that are present. Though they are living in water, air is a necessity, and the larvæ come to the surface to breathe. Like other less harmful insects, some of the larvæ are provided with air siphons in their tails. The *Culex* that convey bird malaria thrust their air siphons through the surface film of water, and hang, head downwards, obliquely through the water. The *Anopheles* that carry malaria from man to man lie parallel to the surface, as they do not possess long drawn-out siphons. This method of breathing of the larvæ is extremely important to dwellers in the tropics, who can thus distinguish between the *Anopheles* that may lead to their ill-health, and the *Culex*, which may cause some slight injury to their birds, but none to themselves.

The early larval life of the mosquitoes is their most vulnerable point. If they escape the effects of chemicals on the water and the attacks of small predaceous fishes to whom they afford dainty morsels, after from eleven to twenty-one days—depending on the warmth and the food available—each larva alters considerably, and becomes a pupa. The latter is distinguished from the larva by its relative quietness and by the development of a huge head. After a few

days' rest as a pupa, the full-grown insect emerges from the pupa case, uses the latter structure as a stand on which to dry its wings, and then flies off to seek a mate and to begin its work of propagating its species. Connected with this latter function of the mosquito is the health or disease of man, for before egg-laying can be accomplished, the female mosquito needs blood to supply the necessary energy.

Near by where the female emerged from the pupa is a small native settlement, with children running about. They seem healthy enough as they play, but among them are many who now harbour malarial parasites (*Plasmodia*) without being much inconvenienced thereby. A quick swoop, a sharp stab, and the mosquito begins to suck the infected blood of the malarious child. Some of the parasites perish almost as soon as swallowed, but others persist. They are of two kinds (Fig. 21, B-D, ♂, ♀). Some are the forms that produce the males (Fig. 21, B, ♂); others are destined to develop into the female forms (Fig. 21, B, ♀). The male progenitors (microgametocytes) are somewhat smaller, have a large nucleus and light-staining cytoplasm, while the females (macrogametocytes) have a smaller nucleus and a larger amount of darker-staining cytoplasm. All other blood forms of the parasite, which are rather numerous, perish in the stomach of the *Anopheles*.

The male organism rounds itself off and its nucleus divides rapidly into about four to six parts (Fig. 21, C, ♂) which move out to the edge of the parent cell. Suddenly, and with explosive violence, the nuclei elongate, and threadlike bodies (microgametes), sug-

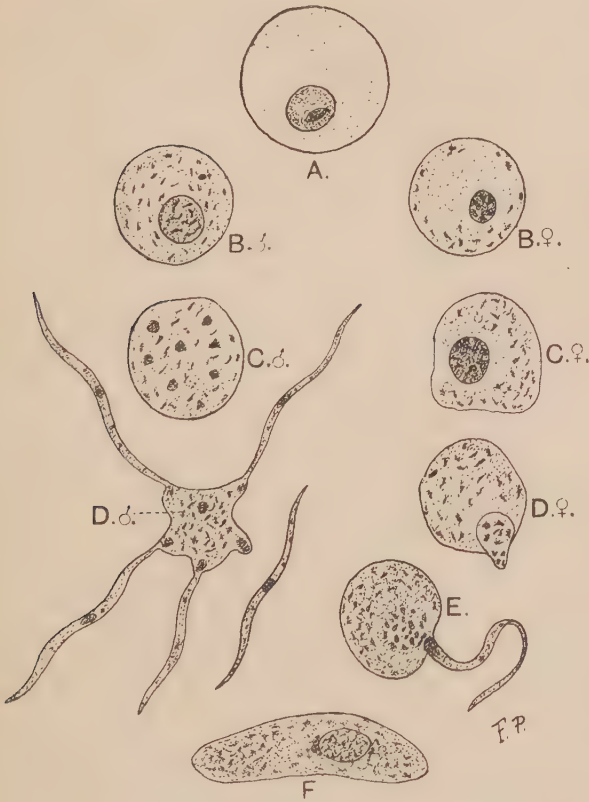


FIG. 21.—STAGES OF *PLASMODIUM VIVAX* IN THE STOMACH OF THE MOSQUITO, SHOWING FORMATION OF GAMETES AND FERTILIZATION

A, The young gametocyte within the blood-corpuscle ; B, ♂, microgametocyte ; B, ♀, macrogametocyte ; C, ♂, microgametocyte with nucleus divided into several parts ; C, ♀, older macrogametocyte ; D, ♂, microgametocyte giving off microgametes (a free male is near) ; D, ♀, macrogamete giving off a small part of its nuclear material prior to being fertilized ; E, fertilization ; F, zygote or ookinete which has become slightly elongated and is capable of free movement. [There should be more diffuse chromatin in D, ♂]

gestive of spirochætes, are formed (Fig. 21, *D*, ♂), each with relatively much nuclear material and a cytoplasmic body. Writhing about, they move rapidly here and there, often dragging the remains of the parent cell with them.

The females (Fig. 21, *C*, ♀), meanwhile, have burst the blood-corpuscle imprisoning them, have given off a small part of their chromatin (Fig. 21, *D*, ♀), and are ready for fertilization. Union with the male, or microgamete (Fig. 21, *E*), is followed by an extraordinary activity on the part of the female, which, once fertilized, proceeds to move actively over the surface of the stomach of the mosquito, and is known as the vermicule, from its wormlike gliding movements, or as the oökinete (Fig. 21, *F*). Gradually it bores its way through the mosquito's stomach and reaches the subepithelial layers, where it becomes rounded (Fig. 22, *A*) and non-motile, but continues to grow, so producing marked bulgings on the outside wall of the stomach into the body cavity. Nor is its increase in size its sole manifestation of activity. Its nucleus begins to divide (Fig. 22, *B*), and the division is repeated a very great number of times (Fig. 22, *C*). The body cytoplasm gradually collects around each nucleus, and the segments of the zygote, now known as sporoblasts, soon begin to be studded with numerous protrusions (Fig. 22, *D*). These take the form of slender sickle-like bodies, which, when fully formed, separate from the residual mass within (Fig. 22, *E*). Each tiny body so formed is called a sporozoite (Fig. 22, *E*), and the cyst produced by the

union of the gametes may ultimately be filled with thousands of these small sporozoites, together with the rest of the cytoplasm, and in addition a blackish

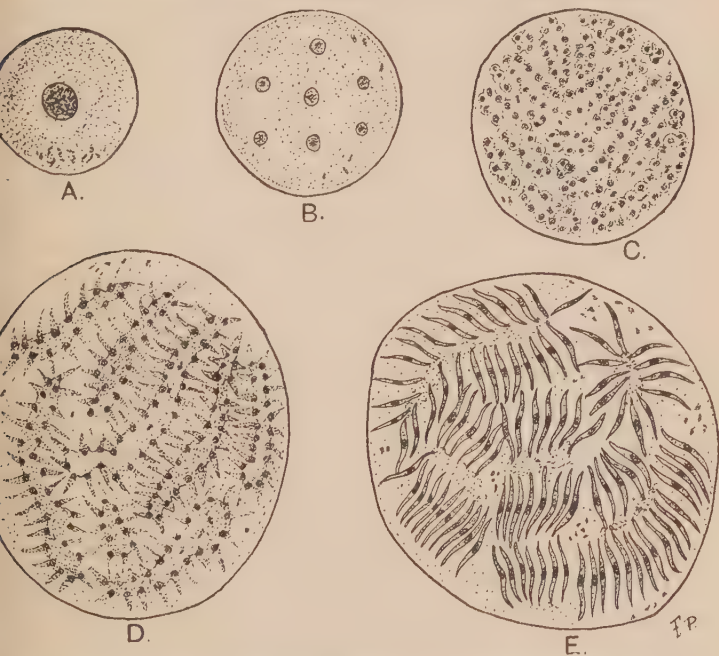


FIG. 22—STAGES OF MALARIAL PARASITE, SHOWING SPOROZOITE FORMATION, AS SEEN IN SECTIONS OF CYSTS FROM THE OUTER WALL OF THE MOSQUITO'S STOMACH

A, Rounded oöcyst formed from the oökinete; B, early stage of division of oöcyst; C, showing division into numerous nuclei; D, the protoplasm beginning to form projections; E, cyst containing many sporozoites

pigment, known as melanin, which is produced by the parent parasites. Ultimately the cyst (Fig. 22, E) bursts, and liberates the contained sporozoites into the body cavity of the host. The sporozoites

travel in the body fluids until they reach the salivary glands of their host, where they collect in great numbers. The mosquito has now become fully infective, and its saliva contains enormous numbers of parasites. The mosquito cycle takes about ten days.

Desiring yet more food, the Anopheline flies away in search of a victim. This time it encounters a white-skinned individual—a child or a man, perhaps—insufficiently protected, while sleeping, by a mosquito-net. The insect stabs some exposed spot, and as it pierces the skin, the saliva, heavily charged with the sporozoites, passes into the wound and reaches the blood-stream. The mosquito having satisfied its needs, flies away to propagate its species. The victim remains quiet, but after some days is destined to know of the action of the insect by undergoing an attack of “fever,” otherwise malaria.

Once within the human blood the sporozoites attack the red corpuscles, and according to the way in which they behave, so is the progress of the disease in the human victim. The malarial parasites are certainly remarkable for their numerous forms and appearances (Fig. 23). Having once invaded a red blood-corpuscle, the sporozoite becomes rounded, and grows at the expense of the corpuscle. In its early life it is distinguished by having a large space in its body, probably caused by a vacuole, which gives it a characteristic “signet-ring” appearance (Fig. 23, *A*). As it grows, the ringlike form becomes less evident and the parasite appears more compact, but is amœboid (Fig. 23, *B*). Gradually it produces the dark pigment (Fig. 23, *B-F*, *p*.) which is so

characteristic of malaria, and the body of the *Plasmodium* appears dotted with granules of melanin. The organism, after attaining its full growth, begins to divide (Fig. 23, C, D), and rosettes of smaller parasites—the merozoites—are formed (Fig. 23, E).

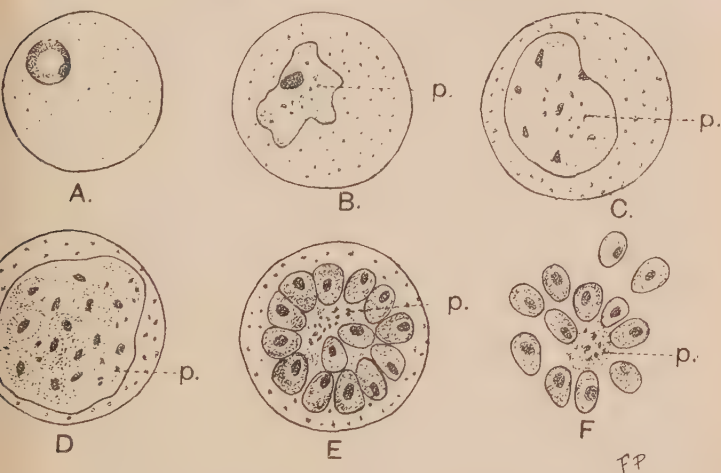


FIG. 23—STAGES OF PLASMODIUM VIVAX IN THE BLOOD

A, Young parasite within red blood-corpuscle, ring form; B, older amœboid trophozoite, with dark pigment masses, corpuscle slightly enlarged; C, a young schizont; D, older schizont; E, rosette of merozoites within the blood-corpuscle; F, part of a rosette of merozoites, surrounding the residual unused part of the schizont, which contains waste material (the merozoites have been liberated by the bursting of a corpuscle); p., pigment

When this stage is reached the enfeebled blood-corpuscle can resist no longer; it disintegrates, and the merozoites are set free into the blood-stream (Fig. 23, F). They soon enter hitherto uninfected blood-corpuscles, where they develop into trophozoites and then become schizonts, that repeat the

rosette formation whereby they themselves originated. At first the number of parasites in the blood is so small as to cause little inconvenience and to be practically undetected, with the result that for about ten days after infection no fever is felt. But as soon as schizogony on a fairly large scale occurs, then the patient feels ill. This period intervening between the actual bite and the onset of fever is usually referred to as the incubation period. Many generations of merozoites may be produced, but ultimately the health of the patient reacts on the parasite and forces the latter to commence some form of propagation other than schizogony, and to produce forms adapted for life in another host. Thus originate the sexual forms of the parasite (Fig. 21), but unless these are taken up by a mosquito—and an Anopheline—they are destined to perish, and the malarial parasites in such cases usually die out. Should a gnat (a Culicine) suck the infected human blood, the malarial parasites are merely digested.

But what of the patient? Now, no less than three kinds of malarial parasites are infective to man, and they each require a slightly different period in which to pass through their trophozoite phase and to become schizonts. *Plasmodium vivax* is the simplest, for it only needs forty-eight hours to accomplish its growing and multiplicative period. As each period of merozoite formation corresponds to an access of fever, the latter is known as “tertian malaria,” and a relapse occurs on the third day. *P. malarix*, on the other hand, needs seventy-two

hours before its schizogony occurs, and on the fourth day the patient has a relapse of "quartan" fever. The worst form of malaria, known as pernicious malaria, is due to the activities of *P. falciparum*, also known as *P. præcox* and *Laverania malaricæ*. This malignant parasite is remarkable in that it divides only in the internal organs such as the spleen, and in that it produces fever at intervals which vary considerably. It consequently causes what is known as malignant tertian or sometimes as irregular or quotidian fever. Very many complications occur in malaria, for a patient may be bitten by mosquitoes containing sporozoites of different parasites, and thus the sequence of attacks may be completely altered. For instance, if two mosquitoes, one carrying *P. vivax* and one *P. malaricæ*, bite a man on the same day, in all probability he will have a relapse on the third and on the fourth day, due to the schizogony of *P. vivax* and *P. malaricæ* respectively, and thus many irregularities are brought about.

Diagnosis of some forms of malarial parasites is very difficult. The milder or benign forms of the parasite are generally found in the form of small rounded organisms, while crescentic gametocytes are present in the pernicious malaria. These "crescents" are bean or sausage shaped, and therefore unlike the schizonts, and so the parasite is sometimes put in a separate genus, as *Laverania*. Tertian and quartan gametocytes are not unlike the schizonts, but they are larger, and also possess more of the dark pigment, melanin. The pigment (Fig. 23, p.)

is set free, in part, during certain stages of fever, and then some of it is taken up by the leucocytes of the blood, which consequently become pigmented. Doctors make use of the discovery of pigmented leucocytes in many cases in which it is difficult to discover parasites in the blood of the patient.

Sometimes the examination of suspected mosquitoes for stages in the life-history of the parasite does not show the characteristic cysts full of sporozoites in the stomach wall of the Anopheline, but instead there are dark blackish bodies about the same size, but harder and coarser. These are the structures that the discoverer of mosquito-borne malaria, Sir Ronald Ross, termed "black spores." Even now there is some uncertainty as to what the nature of these black spores really is, but in all probability they represent cysts that have failed to break through into the body cavity, and so have perished in the walls of the stomach. Some workers believe them to be Protozoa belonging to the genus *Nosema*, and then they are regarded as parasites of the malarial parasites.

It is very important, in dealing with insect-borne diseases, to determine whether the winged carrier is able to transmit the disease to its progeny, and also whether the invertebrate, once infected, remains infective for life. Little is known of this aspect of the malaria-transmitting Anophelines, but so far no evidence of hereditary infection has been found, and experiments are lacking as to the period during which the fly remains infective. The adult male fly lives only a very short time after mating. The

life of the female has been estimated at from two to many weeks. This time varies with the duration of the egg-laying period, and also with the facilities for the same. There seems great probability that a mosquito, once infected, remains infective for life, but actual experimental demonstration of this opinion has not been made.

Malaria is widely distributed. No continent is free from it, and the more detailed records of the present day tend to show that it is far more widely spread than was suspected. Further, it is not spread by one species of mosquito alone, but many Anophelines are incriminated, and several kinds have been caught in the same district and found to contain the characteristic sporozoites in their salivary glands. Europe, Italy, Greece, Spain, and Portugal, all have malarious districts. Throughout Africa the Anophelines are distributed, and native children, mostly between the ages of five and ten, act as living reservoirs of the parasite. Many parts of India, even in the more temperate areas, are unfit for European occupation permanently, and the barracks of European and native troops alike in certain parts, particularly in the northern district, have acquired a sinister reputation. Southern Asia generally is malaria-ridden to some extent, particularly in low-lying districts, where water is unable to drain away. The interruption of the world's commerce by the repeated failures of the attempts to cut the Panama Canal, and the lack of development of the abundant vegetable and mineral resources of the Amazon and Orinoco valleys, are largely due to

the joint deadly action of the scourges of malaria, dysentery and yellow fever. The southern part of the United States, and the West Indies to some extent, have been hampered in many ways by the death-rate due to malaria, though preventive measures during the last few years have made conditions far more endurable. Even Australia is not immune, for malarious areas are known around the northern and eastern coasts.

England in the Middle Ages was a great sufferer from malaria, but the stories of the agues, marsh sickness, and remittent fevers are now little more than legendary. Ague still lingers in the Fens, and within the last few years we have not only seen malarial parasites in the blood of children suffering from ague, but have been able to secure *Anopheles* in whose stomachs cysts occurred, and whose salivary glands teemed with sporozoites. Species of *Culex* are considerably more common in England than are *Anopheles*, but in this case the larvæ of both *Anopheles* and *Culex* were also secured, bred out, and the adults identified. The mosquitoes were *Anopheles maculipennis*.

The menace of malaria in England is at present slight, but it is different in other countries. Preventive and remedial measures are necessary. The early researches of Ross, Stephens, and Christophers, more especially in India and Africa, have laid the foundations of all subsequent work on these lines. Briefly, the methods to be adopted are directed firstly to the destruction of the mosquito; secondly, the use of quinine to prevent recurrences of malaria; thirdly, segregation of the European dwellings from those of

the natives, and especially prevention of the access of infected native children into European households.

Since Ross's famous discovery of the part played by the mosquito in the spread of malaria, many attempts have been made at mosquito destruction. The weak point in the life-history of the mosquito or gnat alike is the larval period. Attempts at destroying the larvæ depend on either the permanent destruction of the insects' breeding-places, or on rendering these places unavailable or too objectionable to permit of either larval life or of egg-laying. Experiments have been made in India, British Guiana,* America, and Africa, by draining the land where possible, and by keeping aqueducts and canals free from floating débris that affords shelter to the larvæ, and thus reducing the numbers of adult insects. These have been partially successful.

In Africa such measures are not so successful as in India. Native villages are near water, and it has been found that the chief haunt of the mosquito in Africa is the native huts. Drainage on the scale necessary for efficient protection from mosquitoes would be most costly, though the use of modern apparatus, such as sand-pumps for filling swamps, has greatly reduced the cost. But much can be done in any malarial district to reduce the number of mosquitoes by preventing the access of the adults to the numerous unnecessary receptacles that are capable of containing water, and so becoming breeding-places. Old tins, broken crockery, unnecessary water-jars—all should be removed.

* See Frontispiece.

The second line of attack is by chemical action, when the larvæ are killed by such substances as paraffin or petroleum, or the breeding-places are made so repulsive by the same, that oviposition cannot occur. The main difficulty in connexion with the use of such larvicides as paraffin and petroleum is that in the tropical and subtropical countries, where mosquitoes most abound, the heat of the sun soon causes the oil to evaporate. Undoubtedly it is most efficient while it is on the surface, and the larvæ are killed rapidly. But about three days after the first application the oil will have evaporated, and as a result larvæ again make their appearance. Consequently, the application of such substances as petrol is inapplicable to large areas such as the swamp-lands of the Southern States or of India. Nevertheless, the method has been used with marked success along the course of the Suez Canal and in the towns on it—both Port Said and Ismailia—and, more recently, along part of the shores of the Panama Canal, though some malaria is still present there.

Still, it is advisable that breeding-places of mosquitoes should be destroyed and not treated, if immunity from attacks is desired. Water is necessary for household use, but water-barrels and cisterns should be made mosquito-proof with wire gauze covers, and should be inspected frequently. The examination should not be casual, but detailed, for the larvæ are very sensitive, and on the least disturbance disappear from the surface and hide in the bottom of the cistern or water-butt. These

receptacles, then, should be siphoned off occasionally, and search made in the lower parts of them for concealed larvæ.

Petroleum is useful where breeding-places cannot be removed or destroyed, and partly refined oil is better than either the crude petrol or the refined product. The first does not spread evenly, the purified oil is less effective. The oil blocks the breathing pores of any larva with which it comes in contact, and the insect dies of suffocation.

Corrosive sublimate, permanganate of potash and crude carbolic acid, all have been used as larvicides at times, but in this connexion it is well to remember the deadly characters of two of these substances, and that cattle may use the water for drinking, with fatal results. Fish used for food also may be poisoned, as well as the mosquitoes. Vegetation, too, may suffer, and such vegetation as is destined for food is frequently only produced by extensive irrigation systems. Petrol, then, seems to be the best and safest larvicide in use, but it can only be regarded as giving temporary relief, and as being subsidiary to drainage operations.

Recently a well-known entomologist has stated very decidedly that, wherever an insect pest exists, there is also some enemy of the pest that will keep it within reasonable bounds. This statement is too sweeping, and it fails to recognize that, though a slayer of the pest may exist, yet its numbers may be such that its efficiency is reduced to a minimum in practice. For instance, the ladybird (*Coccinella*) is a well-known slayer of greenfly (*Aphides*), but its

numbers are too few to make much impression on the progress of "blight" on roses and beans in England. Such is also true of the mosquito, but the destroyer is found in the form of certain small fish, known as "millions," inhabiting muddy swamps, in Africa more particularly. These fish eat the larvæ greedily, but even in their natural haunts they are unable to gain access to all the spots where the mosquitoes breed, and consequently are unable to completely "destroy the destroyers." Reliance on fish and other animals to keep down mosquitoes is only inviting disaster in most cases, or if the extermination is attempted on a large scale there are sure to be numerous escapes.

All fish do not eat mosquito larvæ. Experimental work with fish as mosquito destroyers in India showed that but few of the common species available were of use in this direction. From fifty to one hundred larvæ were placed in tanks, and two or more fish put with them. The best results were obtained with young *Barbus*, which ate all the larvæ within a few minutes. With the catfish and *Trichogaster* the larvæ slowly disappeared, while *Polyacanthus* and a small adult carp made no use of the larvæ as food.

Nevertheless, places in West Africa are known to be free from mosquitoes, and any larva seen is greedily devoured by the fish in the water, and even in the mud along the banks of the stream. The small fish known as "millions" are also sent from place to place in the neighbourhood of the Nile Valley for use in mosquito destruction.

The second method of combating malaria lies in individual preventive measures and, to some extent, anticipatory measures. So far, the most effective method of killing the malarial parasites, once they have gained access to the system, consists of the administration of quinine. A small dose of quinine daily not only kills any parasites present, but also prevents the development of the parasite if it gains access to the blood. Excess of quinine is to be avoided, as with all other drugs. The use of quinine as a preventive is necessary in highly malarious districts, and when used systematically and efficiently is not dangerous. But if a patient suffers from constant malarial attacks in spite of taking quinine, the use of the drug should be discontinued, for under such conditions its use may precipitate an attack of blackwater fever. The latter malady is probably of malarial origin, and is present only in regions of intense malaria.

Again, personal care is necessary to avoid mosquito-bites. This can be done by the use of good mosquito-nets, kept in thorough repair. A few years ago (1898-1902) some members of the Royal Society's Malarial Commission, investigated some of the worst malarial districts of West Africa and India without contracting infection, and they consider that attention to their mosquito-nets and their scrupulous use saved them. The nets should be large enough to tuck well in under the mattress, and should be edged with a solid web of canvas or cloth, so that if a limb is pressed against the net the proboscis of the mosquito cannot reach

it. Thorough repair should be insisted upon, and on no account should the net be allowed to touch the ground, as mosquitoes collect in its folds, and may be set free within it instead of being kept outside.

The segregation of European dwellings from those of the natives appears to be a most effective measure for the prevention of malarial attacks in Africa. Among African children under the age of fifteen there is a widespread malarial infection, and parasites carried from the native to the European is the chief cause of malaria among Europeans. The main source of infected mosquitoes in Africa is the native hut, and in some parts of India similar conditions prevail. In India the usual arrangement is that European dwellings are separated from the native bazaars, but in many parts of Africa little or no attempt is made to separate the dwellings. Wherever it has been done, the malaria rate among the Europeans has decreased enormously. Accra, on the Gold Coast, had one of the worst possible reputations as a home of malaria, and an alarming proportion of the Europeans there succumbed to it. But a resolute attempt was made to stamp out malaria among Europeans by removing them to a higher district away from the native quarters. The result is that the suburb of Accra known as Victoria-borg is often considered the healthiest place on the West Coast. There is a marked contrast with what obtains in Freetown. European and native quarters exist side by side there, and the natives are perpetual reservoirs of malaria. High country alone cannot

be relied on, for Anophelines occur in the highlands around both Freetown and Victoriaborg. The great precaution is the exclusion of infected natives from the immediate neighbourhood of the European quarters, and it is believed that a distance of a quarter of a mile from native huts would suffice to protect against infected mosquitoes. As the evening is the main time when the insects bite, business could be transacted in the town during the day, and the Europeans remove to the segregation area for the evening.

What are the chief mosquitoes that carry malaria? The names of the various Anophelines seem to be in a very confused state, and are still under revision. In Asia they have been grouped roughly into four classes, according to their breeding-places. The first group seek open water where there is much aquatic vegetation, the habitats favoured being ponds, lakes, river-banks, and swamps. Two mosquitoes, *Myzorrhynchus sinensis* and *M. barbirostris* breed in such places, and the first-mentioned has been proved experimentally to be a carrier. The second group are conveniently described as "stream-breeders," and frequent strong-running streams with grassy edges, and irregular ditches also furnish suitable breeding-places. Three important carriers of malignant malaria (tertian) haunt these situations—namely, *Myzomyia culicifacies*, *M. listoni* and *M. christophersi*. *M. culicifacies* is probably the most active carrier of the malignant tertian parasite in India. The third group of mosquitoes include those that frequent clean pools with green algæ, especially those left in

river-beds during the hot season. These include *Nyssorhynchus fuliginosus*, *N. theobaldi*, and *Anopheles lindesayi*, the first two of which have been proved to be carriers of malignant tertian malaria. Lastly, the commonest mosquito of Africa, and almost the commonest of India, *Myzomyia rossii*, together with *Neocellia stephensi*, breed in small muddy pools. The former, which is not infective, is said to be easy to rear in captivity, and a gravid female will very readily deposit her eggs on some damp mud. The latter prefers small quantities of water, and breeds for choice in old tins and pots. The above mosquitoes are among the more widely distributed ones, but there are many other species in India and Africa, some convicted (*e.g.*, *Pyretophorus costalis*) and others under grave suspicion of carrying malaria. To sum up, the wisest plan is to regard all mosquitoes as possible carriers of malaria, and to adopt anti-mosquito operations against them.

Human beings are not the sole sufferers from infection with Plasmodia of various species, for birds are attacked by "bird malaria" due to the operations of *Plasmodium relictum* or *P. præcox*, both names being in use. Very frequently Labbé's name of *Proteosoma* is used for these organisms, but this name, unfortunately, has not official sanction. The life-history of the bird malarial parasites follows on the same lines as that of human malaria, if the gnats (species of *Culex*) are substituted for mosquitoes as the carriers. The parasites living in the blood of the birds are rather compact, and displace the nuclei of the avian red blood-corpuscles harbouring them.

Other parasites, belonging to the genus *Hæmoproteus*, are found also in the blood of birds. *Hæmoproteus columbæ* occurs in pigeons, adults and nestlings alike being attacked. A fly known as *Lynchia*, which is a winged member of the Hippoboscidae, to which group the grouse-fly and the sheep-ked belong, is responsible for the transference of the parasite. Like the grouse-fly, it hides among the feathers, its wings pressed close to its body, and sucks blood vigorously. Nestlings are favoured by it, as their more delicate skins are less difficult of penetration, and the young birds may show infection before their parents, as they have less chance of dislodging the flies by flight. The life-history of the *Hæmoproteus* is rather like that of the *Plasmodia*. When the gametocytes are ingested by the *Lynchia*, the gametes form rapidly and fertilization occurs. By some means not at present fully elucidated, the zygote (or ookinete) is inoculated by the fly into the blood of the bird, where it infects the leucocytes, causes them to grow larger in the lungs, and itself divides into many tiny bodies, often called merozoites. The term sporozoites would seem to be more appropriate, seeing that they apparently result from the division of the fertilized macrogamete. The infected leucocytes finally rupture or disintegrate, and the swarms of minute, amœboid merozoites are thus liberated into the blood-stream, where they proceed to infect the red blood-corpuscles and to grow into halter-shaped gametocytes, once called *Halteridium*.

Finally, before leaving these parasites inhabiting blood-corpuscles, mention may be made of the

Leucocytozoa, especially those inhabiting the blood of birds. These organisms may produce peculiar deformities of the cells they inhabit (Fig. 24) so that the latter appear spindle-shaped and deformed. The male and female mother cells are most common

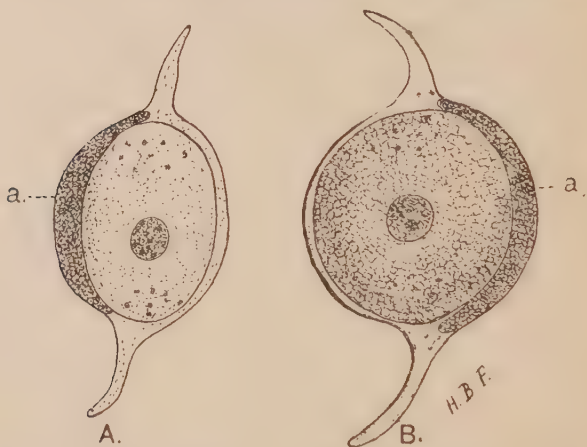


FIG. 24—MALE AND FEMALE GAMETOCYTES OF *LEUCOCYTOZOÖN LOVATI*, FROM THE BLOOD OF THE GROUSE

A, Microgametocyte, with pale-staining cytoplasm and rather granular nucleus; *B*, macrogamete, with deep-staining cytoplasm and more vesicular nucleus with karyosome (the host cell has become spindle-shaped in each case, with its nucleus [*a*] pushed to one side by the parasite)

in the circulating blood. The microgametocyte (δ) (Fig. 24, *A*) is smaller than the female mother cell, has a more granular nucleus, and feebly staining cytoplasm. The macrogamete (Fig. 24, *B*) is rather larger, has much more granular cytoplasm, and a smaller, more vesicular nucleus. The full details of sporogony are not known. Until 1910 the

method of multiplication of the Leucocytozoa was unknown. In that year, the investigation of the

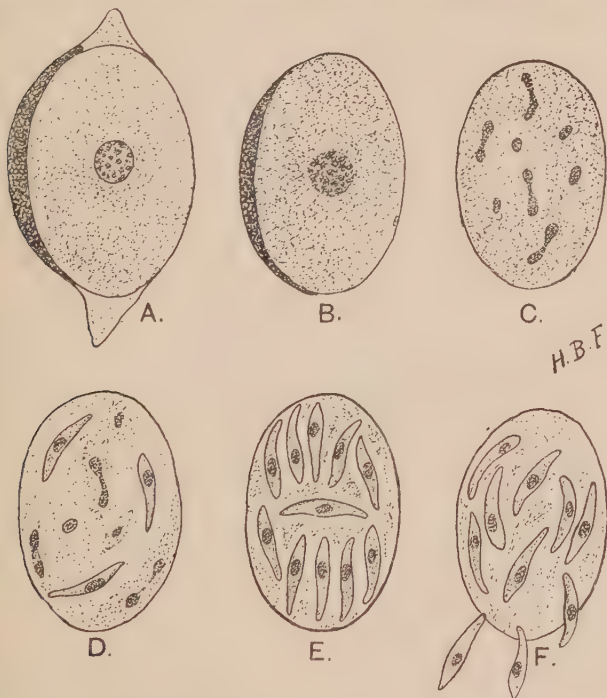


FIG. 25—SCHIZOGONY OF LEUCOCYTOZOÖN LOVATI, AS SEEN IN SMEARS OF THE SPLEEN OF GROUSE

A, Schizont, with the remains of the host cell at either end and host-cell nucleus to one side; *B*, uninucleate schizont, with nucleus of host cell only remaining; *C*, schizont showing nuclear multiplication; *D*, schizont in process of forming merozoites; *E*, merozoites fully differentiated; *F*, merozoites escaping

Leucocytozoön of the grouse showed that schizogony of the parasite occurred in the spleen of the bird. The schizont (Fig. 25, *A*, *B*) is intermediate in

character to the gametocytes. Its nucleus divides into a number of parts (Fig. 25, C) and gradually eight to fourteen small merozoites (Fig. 25, D-F) are formed within it, and are ultimately discharged into the blood, where they penetrate new host cells (Fig. 26). It is probable that the bone-marrow of the host also would show similar stages of the parasites. There are many *Leucocytozoa* in different birds, and the means whereby infection is brought about is



F.P.

FIG. 26.—YOUNG FORM OF *LEUCOCYTOZOÖN LOVATI* THAT HAS RECENTLY PENETRATED ITS HOST CELL AND HAS DISPLACED THE NUCLEUS TO ONE SIDE

little known. It is possible that the grouse-fly, *Ornithomyia lagopodis*, transmits *Leucocytozoön lovati* of the grouse, but the experimental work is still in progress.

Tortoises, snakes, lizards, and amphibia, as well as some mammals such as squirrels and mice, harbour blood-parasites somewhat resembling the *Leucocytozoa* of birds, but space prevents giving any more details of them in the present work.

There is, however, much importance attaching to the study of the life-histories of the parasites of lowly organisms, and the value of such study is perhaps

emphasized by mentioning that the discovery of the relation of the mosquito to the malaria resulted from the patient work of Ross on the malarial parasites of birds, and the interrelation of the gnat and the bird. This knowledge once acquired, the application of it to the human disease was relatively easy, and the adoption of preventive measures in relation to mosquitoes has led largely to the triumph of man over malaria.

It may be of interest to add that the malarial parasites have been cultivated recently by adding a very small quantity of a sugar, called glucose, to malarial blood taken from the human body, and then kept at blood-heat in a tube inside an incubator. The multiplicative cycle of the malarial parasite, as seen in the blood, is then passed through in the culture tube. The method is also applicable to another blood-parasite, *Babesia*, found in animals. By the study of such cultures it is hoped to learn more about possible immunity against malaria in the future.

CHAPTER VI

COCCIDIOSIS, THE FOE OF THE POULTRY YARD

RECENTLY great attention has been directed towards poultry-rearing, partly from the point of view of increasing the availability of poultry for food at a cheaper rate, and partly with the idea of regulating the production of both table-birds and eggs, so that a constant supply of both, in their best condition, can be assured. The problem of disease, and especially the cause of "mysterious" sudden deaths among poultry, together with the reason why some birds, though they feed heartily, never put on flesh, but remain thin and unhealthy, has confronted not only the rearer of domestic poultry, but also the game preserver. The latter, again, often cannot account for great dwindling among his grouse, pheasants, and partridges. The broods have hatched out well, yet when the birds are half grown, the numbers have dwindled to very small proportions, though climatic conditions and food-supply have not been such as to justify the great decrease observed. Among turkey breeders, especially in the United States, the turkey poults succumb

suddenly with but little indications beforehand as to disease, and in England young fowl-chicks and three-parts-grown pullets have been known to die in hundreds within a few days.

Though such havoc has meant very serious financial loss both to moor-owners and to poultry-raisers, yet the cause of the trouble, particularly among young birds, received very little attention until 1908, when one of us, working with the Grouse Disease Inquiry, investigated the cause of the dwindling of young stock, and found that the deaths of the grouse-chicks were due to a minute protozoal parasite known as *Eimeria avium*. Further work has shown that the maladies known to poultry-breeders as "white scour," "scour," "white diarrhœa," and, latterly, "enteritis," are due to the same organism.

The genus *Eimeria* is not restricted to birds, however, for another form infects and kills rabbits; yet another is parasitic in cattle, and a few cases are known in which a parasite similar to that of the rabbit has produced fatal effects in human beings. The human parasite is possibly the same as that which infests rabbits, and there is the likelihood that the eating of the livers of rabbits suffering from coccidiosis has resulted in its transference with fatal results to the human host. The livers of such infected rabbits show white spots filled with a milky fluid. The great range of distribution of these parasites, then, is sufficient to invest them with considerable interest, and this is augmented by an investigation into the many forms assumed by the

parasite and by the intimate relation that exists between it and its host.

If a small piece of excrement, about enough to remain on the tip of a pin, is taken from a grouse or fowl victim of coccidiosis, rubbed in a drop of water, and the liquid examined microscopically, a number of small, oval, shining bodies are seen mingled with the vegetable débris. Dust from plants in the neighbourhood (*e.g.*, heather sprays) will often show these same bodies under the microscope. Every one of these oval structures or cysts is capable of forming four more, termed spores, within itself, and concealed in each of the four spores are two malignant germs, ready to issue from the spore under the influence of the digestive juices of a bird that has swallowed the spore. Once set free, they commence their work of destruction of the intestine, and by their enormous powers of multiplying within the lining of the gut soon reduce it to a structureless pulp (Fig. 27). Digestion is thus deranged, the whole system becomes affected, emaciation and anæmia proceed apace, and ultimately the victim dies.

Such is the usual course of affairs. Externally there is little at first to distinguish a healthy from an infected chick, but as the disease proceeds, great loss of weight occurs. This is very marked in some cases. For instance, of two sister chicks of the same age and originally of the same weight, one became infected and the other remained healthy. At the time of death of the infected bird its weight was 5 ounces, while its healthy sister chick weighed

22 ounces. At the early stages of disease the birds stand about in little groups and utter plaintive cries. They often droop their heads, but when food or

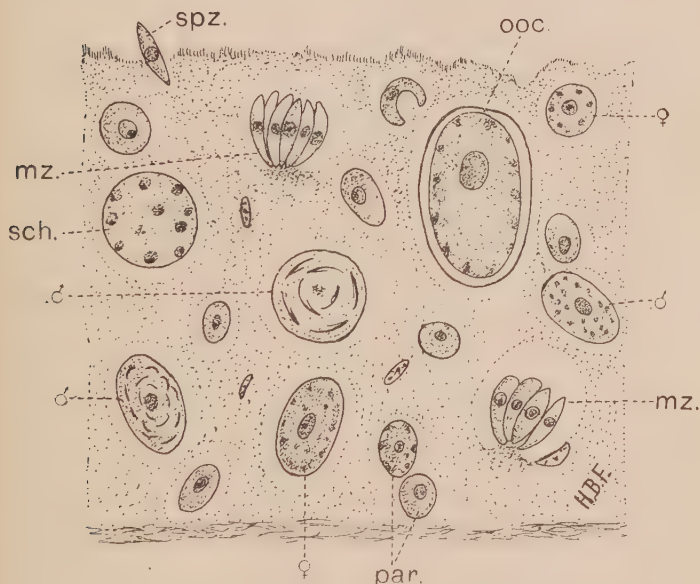


FIG. 27—PORTION OF THE GUT (CÆCUM) OF A GROUSE INFECTED WITH *EIMERIA AVIUM*, SHOWING THE LINING EPITHELIUM RIDDLED WITH PARASITES. MANY STAGES IN THE LIFE-HISTORY OF *EIMERIA AVIUM* ARE SHOWN IN SECTION THEREIN

par., Parasite; *spz.*, sporozoite, or primary infecting germ; *sch.*, schizont, or dividing form; *mz.*, merozoites, or daughter forms; ♂, microgametes (male elements) attached to the microgametocyte (male mother cell); ♀, macrogamete (female); *ooc.*, oöcyst

water is given them, will eat or drink greedily; but in spite of taking large quantities of food they become thin and make little progress. The muscles of the breast and legs particularly show wasting.

In addition to loss of weight, the birds become markedly anæmic, the comb, wattles, and cere being pale and bloodless. The feathering is weak compared with that of healthy birds, and the leg-feathering often is ragged. The quills lose their rigidity to some extent; the sheen on the covert feathers is less developed, and the replacement of nestling-down by ordinary feathers is much retarded in diseased birds.

Owing to the attacks of the parasite on the mucous membrane of the food-canal, and especially of the intestine, digestive troubles occur, and the fæces voided by the infected bird are an index of its condition. The dejecta are very pale, softer than usual, and often of a sulphur yellow colour, occasionally with a very offensive odour. At times the unfortunate birds have a discharge from their eyes and ears, and a peculiar bluish tint appears in the skin, being especially noticeable around the eyes. The death of the victim of coccidiosis is often sudden, and with little indication that decease is imminent; in fact, the birds may be feeding a few moments before death occurs.

Before detailing the direct effects of the parasite upon the internal organs of the host, it would be well to consider the life-cycle of the destroying organism and the interrelation that exists between the parasite and its host.

In connexion with the life-cycle of *Eimeria avium*, it must first be explained that while the disease is known as coccidiosis, the parasite causing it is more correctly known as *Eimeria avium*, rather than *Coccidium avium*, the name *Eimeria* having been used

for such organisms prior to that of *Coccidium*, but coccidiosis is the name established for the disease. As before mentioned, the fæces of birds suffering from coccidiosis contain numerous oval shining bodies. Each is about $\frac{1}{100}$ the size of a grain of wheat, and possesses a very tough, resistant coat. These bodies are known as oöcysts, or, more popularly, cysts. After a short time, under favourable conditions of warmth and moisture, four other oval bodies, each with its own resistant coat or sporocyst, develop within the oöcyst (Fig. 28, S). Each of these is a spore, and ultimately within the spore two primary infecting germs, or sporozoites (Figs. 27, *spz.*; 28, *A*), are produced, the broad end of the one lying near the narrow end of the other.

The fæces crumble into dust, and, carried by the wind, the oöcysts find their way to the pools or tarns at which the grouse drink. When the wind drops, they are deposited as fine dust in the water or on the tender shoots of the heather that is the diet preferred by the bird. The contamination of the drinking-water also is aided by the rain washing excrement into the pools. When the cysts are taken up with the food or drink of their host, they resist the crushing by the gizzard and the action of the digestive juices until they are passed into the duodenum. Here a very different state of affairs occurs. Under the powerful action of the pancreatic juice poured into the first part of the gut—the duodenum—aided by the increase in temperature, the tough cyst walls are softened, and the sporocysts partly or entirely escape, only to be softened in their turn. The two sporo-

zoites within each spore twist until they lie parallel, in the position easiest for emergence, and when they escape, they glide away with sinuous undulatory movements over the intestinal surface. Each tiny germ (Figs. 27, *spz.*; 28, *A*) is extraordinarily active, and is aided in its movements by manufacturing a surface for its own evolutions, by secreting a gelatinous substance which provides it with a slippery surface on which it glides forward. Small as it is, only about $\frac{1}{2500}$ inch, it contains a small nucleus of distinct, uniform structure. The sporozoite remains free only a very short time in the lumen of the gut, but rapidly attaches itself to an epithelial cell, and proceeds to bore its way inwards (Fig. 27, *spz.*). Once within, the parasite curls on itself, gradually loses its elongate form, and becomes rounded (Fig. 28, *B, C*). It grows steadily at the expense of the host cell, and soon the latter becomes greatly atrophied, its nucleus is much displaced, and the parasite lies in a clear space within the host cell (Fig. 27, *par.*). This passive, feeding stage of the existence of the organism is known as the trophozoite (Fig. 28, *D*).

Growth continues for some time, but ultimately a period is reached when the parasite ceases to feed and prepares to perpetuate its kind and to increase its numbers within the same host. The nucleus begins to separate into two portions, and no sooner is the division accomplished than it is repeated until eight to fourteen portions are formed (Figs. 27, *sch.*; 28, *E*). Occasionally, when there is a great abundance of nourishment and much space available, twenty daughter nuclei may be produced, while when

food is scarce and the space small, as few as four may be produced. They are not arranged haphazard within the body of the parent parasite, now known as the dividing or splitting form—the schizont, but gradually pass outwards to the edge, where they become arranged like beads on a girdle, at the circumference (Figs. 27, *sch.*; 28, *E*). Some of the nuclear substance of each portion concentrates to form a more compact part of the daughter nucleus, and little by little the greater part of the protoplasm collects around these daughter nuclei (Fig. 28, *F*). The result then resembles that seen in an orange, all the daughter parasites (technically termed merozoites) being arranged like the segments of the orange (Figs. 27, *mz.*; 28, *F*, *G*). The daughter forms remain together for a short time, but finally separate. Each is a small, wormlike organism, strongly resembling the sporozoite, though it is somewhat stouter, and possesses a more marked nucleus than that of the primary infecting germ. The merozoites (Fig. 28, *H*), when they have reached the surface of the gut, penetrate new host cells in the same way as the sporozoites did, grow, and finally destroy their host cells, and ultimately propagate by division again. Progressive destruction of the lining of the gut thus ensues, and when the parasites reach the blind guts, or cæca, which are very long in the grouse, and attack their lining membrane, the malady becomes much more acute. In fact, birds may recover from coccidiosis in the first part of the gut—the duodenum—and then succumb to an attack in the cæca.

But multiplication of numbers within the one host

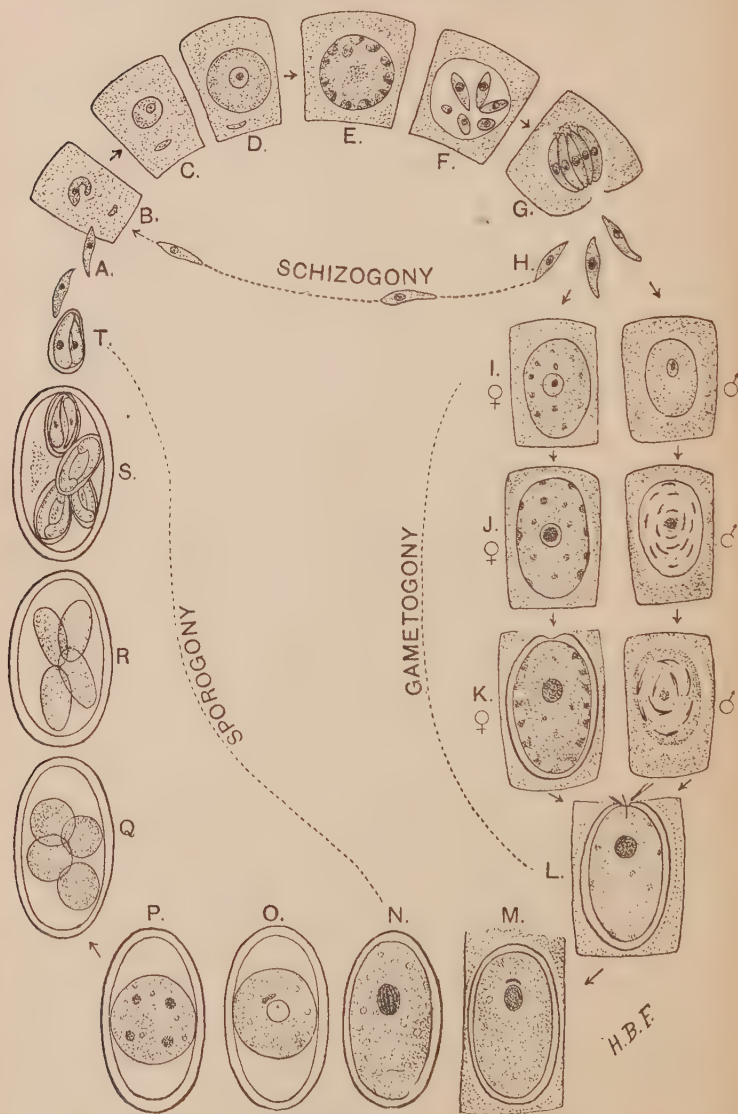


FIG. 28—(For description of Diagram see next page)

is not enough. The parasite needs to complete its own development and to assume a form capable of passing to a new host, otherwise the race would come to an end. Consequent on the physiological necessities of the parasites, as well as to a reaction against them on the part of the host, certain trophozoites cease to become schizonts, but their latent potentialities are aroused, and sexual differentiation begins.

FIG. 28—DIAGRAM OF LIFE-CYCLE OF *EIMERIA* (*COCCIDIUM*) *AVIUM*

B-H, Illustrate the asexual reproduction (schizogony) of *E. avium*. Epithelial host cells diagrammatically outlined. *I-L*, Illustrate the production of sexual forms (gametogony). *N-T*, Illustrate spore formation (sporogony). *A*, Sporozoite or primary infecting germ, which penetrates the epithelial cell of the duodenum of the host. *B*, Sporozoite curving on itself before becoming rounded within the host cell. *C*, Young, growing parasite. *D*, Fully grown parasite (trophozoite). *E*, Schizont, with numerous daughter nuclei peripherally arranged. (Seen in transverse section.) *F*, Schizont showing further differentiation of merozoites. *G*, Merozoites, arranged like segments of an orange, about to issue from host cell. *H*, Free merozoites. *I*, ♀, Young macrogametocyte with coarse granules. *I*, ♂, Young microgametocyte, with fine granules. *J*, ♀, Growing female mother cell, showing chromatoid granules. *J*, ♂, Microgametocyte, with nucleus divided to form a number of bent, rodlike portions, the future microgametes. *K*, ♀, Macrogamete which has formed a cyst wall for itself, but has left a thin spot for the entry of the microgamete. *K*, ♂, Microgametocyte, with many biflagellate microgametes about to separate from it. *L*, Fertilization. One microgamete is shown penetrating the macrogamete, while other male cells are near the micropyle, but will be excluded. *M*, Fertilization. The male pronucleus is lying above the female chromatin. The other microgametes have degenerated outside the oöcyst. *N*, Oöcyst (encysted zygote), with contents filling it completely. *O*, Oöcyst, with contents concentrated, forming a central spherical mass. Many such cysts seen in infected caecal droppings. *P*, Oöcyst, with four nuclei. *Q*, Oöcyst, segmented to form four round sporoblasts. (As seen in fresh preparations.) *R*, Oöcyst with four sporoblasts, which have grown oval and are becoming sporocysts. *S*, Oöcyst with four sporocysts, in each of which two sporozoites have formed. *T*, Free sporocyst or spore in which the sporozoites have assumed the most suitable position for emergence

Some of the growing forms become larger than the schizonts, and store up large quantities of reserve food within their substance. These parasites are destined to become female forms (Fig. 28, *I*, ♀). On the other hand, some are smaller, and contain no reserve of food. These are the progenitors of the male parasites (Fig. 28, *I*, ♂).

The potential female forms (Fig. 28, *J*, ♀), which are scientifically termed macrogametocytes, are large. They rapidly accumulate food, which is stored in the form of faintly yellowish granules, and they also secrete substances that are for future use in making a protective coat or sheath (Fig. 28, *K*, ♀). The latter have a strong resemblance to nuclear substances, and as they stain intensely, they are known as the chromatoid granules (Figs. 27, *oöc.*; 28, *K*, ♀). When the female mother cell is almost mature, it passes its chromatoid granules outwards to its surface, where they fuse together, become chemically altered, and form the coat known later as the oöcyst (Fig. 28, *K*, ♀).

Meanwhile, the cells destined to give rise to male organisms have remained finely granular, and instead of expending their energies on food storage and wall construction, have utilized it in nuclear division. The nucleus divides rapidly, and smaller collections of nuclei (Figs. 27, ♂; 28, *J*, ♂) are produced, so that the surface of the microgametocyte (commonly called the male mother cell) becomes covered with a meshwork of nuclear fibrils (Fig. 28, *J*, ♂). Each fibril is made of granules, and at first is looped. The loops concentrate and gradually become slender,

rodlike bodies (Figs. 27, ♂ ; 28, *K*, ♂), around each of which a minute quantity of cytoplasm collects and is continued outwards as two fine, trailing threads or flagella (Fig. 28, *K*, ♂). A very large amount of the body substance of the male mother cell is not used at all, but remains behind when the male cells (microgametes) break from the parent and swim away in search of the female (Fig. 28, *L*). Though they are very minute, only about $\frac{1}{8000}$ inch in total length, the males are capable of very rapid motion. They move with a gliding serpentiform action, and when attracted to the female by some chemical substance secreted by it, behave with great vigour.

Fertilization has been seen in life. Prior to the actual fusion of the sexual forms, the female parasite has thickened its cyst wall, but has left one spot in it much thinner than the rest. Vigorously lashing their flagella, several males approach this weak spot, or micropyle, and attempt to penetrate within. One at length succeeds, and the stimulus of its entry has the effect of producing almost immediate thickening of the micropyle and exclusion of its companions (Fig. 28, *L*), which after more vain attempts weaken and die in the mucilage usually to be found around the micropyle. The flagella of the male take no further part in the development, but are discarded. The nucleus of the male, however, spirally bores its way inwards until it comes to rest above the nucleus of the female (Fig. 28, *M*), when, by a somewhat complicated process, the intimate mixture and fusion of the two nuclei is accomplished

(Fig. 28, *N*). The fertilized oöcyst (encysted zygote or cyst) now enters upon a series of changes leading to spore-formation, the stages in the life-history being known as sporogony (Fig. 28, *N-T*).

When the stage of oöcyst formation is reached, the perpetuation of the parasite is ensured, and there is the possibility of the recovery of the host, for if the oöcysts are discharged from the body and there are no young merozoites to continue the growth, the injured gut epithelium may be able to form again, and then the bird recovers. The systematic examination of the droppings of the bird thus can be used as a rough index of the possibility of the recovery or otherwise of the bird. This matter will be more fully discussed later. Examination of a minute portion of fæcal matter when freshly voided usually shows all the oöcysts with their contents filling them entirely (Figs. 28, *N* ; 29, *A*). After a short time the contents of the cyst begin to contract, and gradually a spherical mass is formed within each oöcyst, a space being left at either pole (Figs. 28, *O* ; 29, *B*). Cysts two to three days old often show complete development, though the stage reached depends partly on favourable conditions. Should the conditions be of the best, the nucleus of the oöcyst divides into two, and this division is followed with extraordinary rapidity by another, so that the oöcyst has four nuclei (Figs. 28, *P* ; 29, *C*). The protoplasm separates at the same time into four ball-like masses (Figs. 28, *Q* ; 29, *D*), so that the oöcyst contains four spheres. These soon elongate and become oval (Figs. 28, *R* ; 29, *E*) and quickly

secrete a coat for themselves, when they are known as the sporocysts or spores. Each oöcyst, then, contains four sporocysts (Figs. 28, *S* ; 29, *F*).

The spores do not remain undifferentiated for long. A rounded or oval shining area makes its

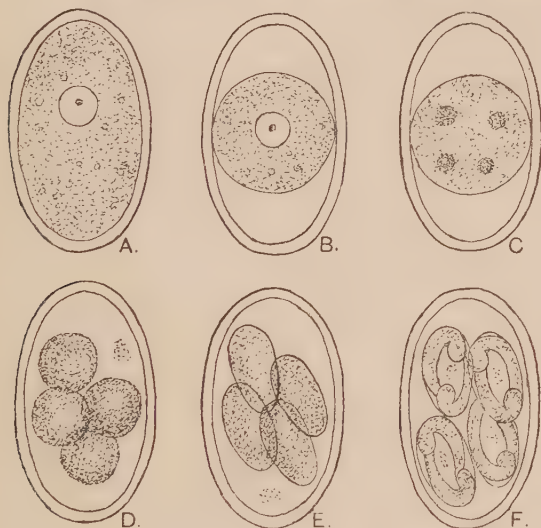


FIG. 29—STAGES IN THE DEVELOPMENT OF THE OÖCYSTS OF *EIMERIA AVIUM*, AS SEEN IN FRESH PREPARATIONS

A, Oöcyst, with protoplasm completely filling it ; *B*, older oöcyst with contents forming a central sphere ; *C*, oöcyst with four nuclei about to form sporoblasts ; *D*, oöcyst with four round sporoblasts ; *E*, four ovoid sporocysts within oöcyst ; *F*, fully mature oöcyst with four sporocysts or spores, each containing two sporozoites

appearance in them, and at the same time the nucleus becomes bowed and dumb-bell-like. The shining area becomes filled with liquid, and the vacuole so produced gradually extends obliquely until it has cleft the protoplasm and nucleus into

two practically identical masses, so arranged that the broad part of the one is adjacent to the narrow part of the other. The two vermiform organisms thus produced in each spore are the two sporozoites (Figs. 28, *T*; 29, *F*) similar to those with which the life-cycle began.

When a fresh preparation containing many oöcysts is examined, variations as to size and shape of the cysts as well as in the arrangement of the contents, will be seen. This is only to be expected, seeing that size and shape are largely dependent on the quantity of food available and the amount of space at the disposal of the parasite. At the commencement of cyst formation, when the number of cysts is relatively few, there is an abundance of food, and the parasites do not suffer from overcrowding. As a result, the oöcysts are well formed and large. When the same host cell is invaded by several merozoites, together or successively (and this often happens), and when at the same time the adjacent cells are also highly parasitized, then there is restriction both in the food-supply and in the space. Squarish or egg-shaped oöcysts of smaller size are often produced under such conditions. Further, when sections are examined, the above reflexes of space conditions and nourishment available are seen. Thus, when the number of trophozoites in any area is unduly large, the schizonts produced do not grow to the normal size and produce eight to fourteen or even twenty merozoites, but remain small, and commonly form about four merozoites. Thus it is seen that two methods of maintaining the constancy

of the numbers of parasites in one host prevail, but the production of many small schizonts is a greater tax on the resources of the host.

The life-history of all well-known pathogenic parasites contains some one stage at which the vitality of the organism is at its lowest, and such a phase is the time at which the recuperation of the host may enable it to destroy its invader. The weak spot in the active life of a coccidian parasite is the sporozoite stage. Should but few oöcysts be swallowed by the bird concerned, and the digestive juices of the latter be vigorous, the delicate sporozoites do not stand so good a chance of evading digestion as they would do if the bird were younger or somewhat more weakly. Hence it happens that coccidiosis is especially fatal to very young birds, though it is far from being unknown among older ones, which may act as reservoirs of cysts.

The onset of sporogony of *Eimeria avium* usually means either the recovery or the death of the infected bird. When the infection has not been acute, the oöcysts pass from the body, and provided that reinfection of the bird does not occur, the internal lining of the gut may be able to regenerate itself, when the bird gradually becomes less anæmic and begins to increase in weight. Sometimes infiltration of connective tissue into the lesions or gaps formed by the parasite aids in the reconstructive processes, and complete recovery may ensue.

On the other hand, certain birds such as grouse possess very long cæca. As before mentioned, daughter forms produced in the duodenum may pass

down the gut and reach these cæca. Cases are known in which birds have recovered from coccidial infection of the duodenum, but have succumbed to that produced later in the cæca. Duodenal infection is quite enough to kill young birds, even when not supplemented by cæcal infection. The larger the number of oöcysts swallowed originally, the greater is the chance of the parasite propagating enormously. In such cases, or where a succession of crops of oöcysts are swallowed by the bird, the intestinal epithelium gets little or no chance to regenerate. Digestive troubles ensue, anæmia and wasting follow, and death ultimately cuts short the career of the host, and also to some extent that of the parasite, since young, developing forms of *Eimeria* perish with their host and rapidly degenerate.

Such is very far from being the case with the oöcysts that have already been fertilized. So far from perishing on the death of their host, they remain within the body, and their further development is aided by the heat produced by the decay of their victim. When at last they are set free by the rapid disintegration of the tiny corpses of birds, such as young grouse or pheasants, they contaminate the soil, and another bird, perchance in search of grit or insects, takes up the polluted soil, and thereby sows within itself the germs of its own destruction. While it is almost impossible to prevent such contamination among wild birds, it is less difficult in the case of domesticated ones. But in all cases it cannot be too strongly emphasized that any corpses found should be burned and not buried. It is not

the immediate contamination of the soil that has to be feared. Worms of all varieties constantly remove soil from place to place; moles and ants aid in renewing the surface and in transportation; rabbits scuttering through heather or other vegetation raise a dust-mist around themselves; and by many other animals, soil or fæces rich in coccidian cysts are scattered over the face of the country.

The wind carries the dust hither and thither, and when it falls, the cysts are deposited on growing heather and in tarns and streams indiscriminately. A rainstorm aids in the process, and deadly fæcal matter is washed into the water-supply so necessary for the vigorous growth of the young animals. Feeding on the juicier young heather-shoots or drinking at their favourite shallow pools, the chicks swallow the spores, and if these are present in any numbers, in about eight to ten days' time the young covey will have disappeared, slain by the unsuspected enemies absorbed with their food.

Wind, food, and water are not the only means of spread of disease. Occasionally veritable flying parasite carriers are encountered in the form of birds which have been infected, but have by some means adapted themselves to the presence of the parasites, and are, to all intents and purposes, not inconvenienced by them. Such birds may be termed "chronics." They are always infected themselves, and periodically void fæces heavily charged with cysts, yet externally they appear healthy. Rarely are symptoms such as thinness, anæmia, or poor feathering marked. But such birds are a very real

danger on the grouse moor, pheasant preserve, or poultry yard, for any young birds feeding with them or reared by infected foster-mothers, ingest the coccidian oöcysts and succumb after a short time. They have been well termed "flying reservoirs of disease." When epidemics occur among young birds, it is always well to examine any old birds associated with them, for the parasite carrier has often been found to be the cause of inexplicable outbreaks among previously healthy stock.

Another feature worthy of note is that oöcysts of *Eimeria avium* can be swallowed by other birds and pass unharmed through their bodies, only to be voided elsewhere and cause incalculable damage. For instance, a bad outbreak of coccidiosis occurred on a certain farm among the fowls. Some sparrows came to the farmyard for grain, and picked up not only grain, but oöcysts of *E. avium*. Visiting other and healthy yards, the excrement of the sparrows was dropped, and contaminated the ground with oöcysts, which naturally were a source of danger, and other outbreaks occurred. Sparrows were shot and examined, and it was shown that they contained oöcysts of *E. avium*, but were not infected thereby. They were, in fact, merely mechanical carriers.

Pigeons also will gather grain wherever they can, and we have personal knowledge of whole pigeon-cotes that have been exterminated by coccidiosis acquired from an infected poultry-run. In the case of domestic poultry kept under cover, the exclusion of small birds such as sparrows can be secured. It is obvious that the danger from such small birds is

much greater among poultry kept on grass runs, where many birds are confined within a relatively small area, than in the case of wild birds that have feeding-grounds more remote from one another.

The *Eimeria avium* of grouse and other wild birds and of fowls in England is restricted to the main alimentary tract, and is particularly found in the duodenum and cæca. But the same parasite is responsible also for a fatal disease among turkeys, in England, on the Continent, and in North America. In America, where enormous numbers of turkeys are bred each year, the disease has caused considerable monetary losses. Both in England and America the turkeys present the same symptoms as described for the other domestic birds and for grouse, and in addition the comb, wattles, and skin of the head present a remarkable darkness and blackish tint that have given the popular name of "blackhead" to the disease. The parasite of blackhead, however, has a wider distribution within its host than the form found in fowls or grouse, for sporozoites or merozoites make their way from the duodenum up the bile-duct and gradually penetrate the liver-substance. They carry out the same asexual and sexual cycle as in the intestine, and little by little, whitish soft spots, filled with a creamy to cheesy fluid, appear in the liver. These patches of abscessed tissue and the fluid are full of oöcysts, which reach the intestine and are voided with the fæces. The infection of the liver only makes its appearance late in the course of the disease, and birds may die of blackhead without any infection of the liver occurring; also

young birds frequently do not have liver infection. Sometimes the infected turkeys have been removed to clean ground and the soiled area used for rearing fowls, with fatal results to the latter. Similarly, turkeys put on ground where outbreaks of coccidiosis had occurred among fowls previously occupying it, have succumbed to blackhead. Mutual infection thus occurs, and soil fouled by turkeys or other fowls should not be used for the rearing of young bird stock of any kind.

In the open country certain coprophagous (dung-eating) flies, such as *Scatophaga stercoraria*, lay their eggs in the droppings of birds, and there the larvæ develop. Larvæ and adults taken from grouse-droppings have been submitted to examination, all possible care being taken to avoid external contamination of the insects, and unchanged oöcysts have been found not only in their alimentary tracts, but in their fæces voided during the time they were kept under observation. A vigorous insect population, then, can aid mechanically in scattering the cysts of the parasite.

“Prevention is better than cure” in all cases, and nowhere does this apply more than in preserving the health of domestic poultry and hand-reared game birds, such as pheasants and partridges. Even in epizoötics among game birds it cannot be too strongly insisted upon that all corpses of birds should be burned and not buried. Every buried bird is a new source of infection, and the polluted soil is distributed in many and unseen ways by earthworms, by round-worms of the soil, by carnivorous beetles,

flies, moles, etc., so that the infection can be spread over a much wider area than was formerly the case.

When birds are living under partially or entirely domesticated conditions, great care should be taken to burn all droppings and to ensure an adequate supply of uncontaminated food and drink. No excess of food should be permitted. It is not only wasteful, but increases the chances of infection. Purity of the food-supply can be ensured in part by using movable boards on which the food can be placed. The boards can then be removed and thoroughly cleansed, while the pens should be so constructed that daily cleaning is possible and easy. Lime-washing of all coops, etc., once a week is useful.

Wherever possible, healthy birds should be taken off infected areas, and the fowl-houses placed in some position as remote as possible from the former ones. The fouled surface soil should then be removed and burned, or thickly treated with quick-lime, which, after about a week, should be well dug into the soil.

It is useless to remove heavily infected stock to fresh places. The very act of removal may spread trouble by infecting new soil if the birds are driven, or by polluting crates and vehicles if they are conveyed, while they almost at once create as bad an environment as they have left. It is far better to destroy such birds and to recommence with new stock on clean ground.

When birds are reared in large numbers, it is a

wise precaution to have the breeding-pens in such a position that they are swept as little as possible by winds coming from runs, etc., of older, and possibly infected, stock. Great care also should be exercised in choosing foster-mothers, especially in rearing pure-bred stock, for a parasite carrier used as a foster-mother would mean almost certain death to her brood. Further, it is advisable to disinfect all eggs before they are set. A solution of 90 to 95 per cent. alcohol (strong methylated spirit will do), has been used for wiping the eggs, and has been found efficacious.

With regard to treatment, it is almost impossible to give any advice in the case of wild birds. Any condition that tends to raise the vitality of the chicks is of service and should be used. Recently some experiments have been completed by us on the treatment of avian coccidiosis by means of catechu. The procedure may be briefly indicated. Ten to fifteen grains of crude catechu are dissolved in one gallon of water. The dark sherry or ale coloured fluid thus obtained is administered to the birds as drinking-water. The solution often darkens in air, but its usefulness is not impaired thereby. The birds drink it with avidity, and rapid improvement follows. The treatment is usually only necessary for about ten days, and a solution containing 10 grains of catechu per gallon is strong enough in most cases. The birds successfully treated were fowls, ducks, pigeons, hand-reared pheasants and grouse in captivity. The treatment, successfully determined by laboratory experiments, was tried on

a larger scale with infected birds on a small covered earth-run, and on a grass-run, and was very successful. It has also stamped out disease on several large poultry - farms, where heavy losses due to coccidiosis had occurred. Although the objection might be raised that catechu is merely an astringent, yet the great success of the treatment up to the present has justified its presentation to the scientific agricultural public.

Other chemical substances, such as 10 grains of sulphate of iron ("green vitriol") per gallon of water, or sodium salicylate in the drinking-water of penned birds, has a tonic action, and by raising the vitality of the birds, renders them the better able to resist the attacks of the parasite.

For the destruction of oöcysts nothing is so efficacious as quicklime. Gas lime, slaked lime, salicylate of soda and nitrate of soda also cause destruction of the cysts, but after longer exposure, their efficiency being in the order of mention. While nitrate of soda needs too long contact with oöcysts to make it of practical value, it must be remembered that it is a powerful plant food, and that its use, in promoting the healthy growth of the plants on which the birds feed, may be of great value by ensuring an easily digested, nutritious, and uncontaminated food-supply.

Coccidia of various kinds occur in other hosts, such as rabbits. The rabbit parasite is much like that of the grouse or fowl. It is named *Eimeria stiedæ*. It seems to prefer the liver to the intestine in some cases, and then large whitish spots, which

discharge a milky fluid, are found in the liver. Sometimes the fluid becomes practically solid, and a white, chalky mass then can be dug out. When diluted and examined microscopically, it is found to consist of myriads of the cysts of the *Eimeria*. The mode of transference to other rabbits is by contamination of the food-supply by the fæcal matter of infected rabbits. Some workers have thought that *E. avium* and *E. stiedæ* are one and the same parasite, but such is not the case. By experiment it has been shown that rabbits fed with food contaminated with *E. avium* have remained quite healthy, and that the oöcysts passed unchanged through their bodies. Similarly, birds given food fouled with ripe cysts of *E. stiedæ* have not become infected. The life-history of the two parasites is similar, but the organisms are distinct, and are in definite relationship with their respective vertebrate hosts.

The life-histories of all *Eimeria* are not identical. *E. schubergi* is found in the common centipede. This parasite has a considerable number of differences from *E. avium*. It is larger, has more merozoites, which are arranged in a rosette, and has spherical cysts and spores. The method of liberation of the spores also follows a somewhat different course.

Among the backboneed animals a number of marine birds, such as gulls, choughs, kittiwakes, and guillemots are liable to coccidiosis, but an *Eimeria* is not the cause of their complaint. This is produced by a coccidian belonging to the genus *Diplospora*, which infests the alimentary canal of these

birds. The life-cycle is much like that of *E. avium* until spore-formation is reached, when two sporocysts only are produced instead of four. To compensate for this, however, four sporozoites are produced in each spore, and thus the ultimate result is eight sporozoites from one cyst, as in *E. avium*.

Coccidiidæ also are responsible for disease among cattle and goats, as before mentioned, but it must be remembered that the development of the parasite may produce the death of the host before its own course is complete, and such is commonly the case in cattle coccidiosis. Here numerous merozoites are shed in the fæces, but cysts are rarely found. The problem of the spread of cattle coccidiosis is therefore one of great difficulty, yet one worthy of attention among those who suffer loss from cattle pest in tropical countries.

Various *Coccidia* are known among invertebrate animals such as insects, flatworms, and molluscs. Hitherto little research has been conducted on the effects of these parasites on their hosts, but we have much evidence that they are far from being harmless—as, indeed, is the case with many other reputedly innocent occupants of the bodies of other animals.

In conclusion, it should be remarked that, as with many other diseases, improvement in the hygienic conditions of life of confined animals seems to offer the best solution of the animal scourge so long known as a malady, and so long misunderstood as to its cause and prevention—coccidiosis.

CHAPTER VII

SOME HARMLESS AND HARMFUL AMŒBÆ

THE study of the simplest forms of living animals usually is commenced with that of the common *Amœba*, which in many respects is an ideal organism with which to begin the study of a single cell. From a harmless and even beneficial life in pond-water to a parasitic and most destructive existence in the human intestine seems a long step, yet such has occurred in the evolution of the race of amœbæ, for to members of the group two dreaded human diseases at least must be ascribed—namely, amœbic dysentery and liver abscess.

Amœbæ are among the most ubiquitous of organisms. From the *Amœba proteus* found among the débris in pond-water it is but a small step to the amœbæ living among moss and liverworts that frequent the banks of streams or live in damp places. Vertebrates frequently absorb such amœbæ with food or drink, for almost any stagnant pool, particularly in the tropics, will furnish some amœbæ, occasionally swarms of them, and certain of these have become habituated to life in the digestive tubes of their hosts. Such a situation provides an abundance of

food, both of the indigestible and undigested food-materials of the host and of a rich bacterial flora. These amœbæ feed passively on the food, are sluggish, and cause practically no harm to the host harbouring them.

Other Amœbæ are not so complaisant. They need protoplasm, not proteid; cell substance, not cell débris; and to satisfy their wants, they penetrate the cell-walls of their host's digestive tract, and within or among the cells of the host they multiply actively. Thus a free-living organism may become first saprophytic, then parasitic, and subsequently pathogenic.

The fate of the pathogenic Amœbæ of man is to be expelled from the bodies of their hosts ultimately in the form of cysts. In the tropics excrement from practically every source is utilized for the manuring of the land, and, consequently, almost every source of water-supply may be contaminated with the cysts of various amœbæ. Green vegetables, and especially salads, are most easily exposed to contamination, and it is a fortunate circumstance that under ordinary conditions relatively few amœbæ are harmful to man. Even fruits, such as strawberries, are not exempt from the suspicion of conveying amœbæ to man, and the greatest care is necessary in dealing with either ground-fruits or vegetables grown under tropical conditions.

Amœbæ generally have a very ill-defined shape, as they are capable of protruding numerous portions of their body-substance as pseudopodia, such protrusions being accompanied by retractions elsewhere,

and being used for progression and food capture. The body shows, at any rate at some phase of its existence, a distinct outer layer, or ectoplasm (Fig. 1, *ect.*),* and a more granular inner layer, the endoplasm (Fig. 1, *end.*). Pseudopodia at first are purely ectoplasmic, and it is only by degrees that the endoplasm flows into them. The number of pseudopodia varies greatly. *Amœba proteus* from pond-water shows several pseudopodia at a time (Fig. 1, *ps.*). The small amœba, belonging to the *limax* group, sometimes found in household water-taps, has a sluglike appearance, for it usually protrudes one pseudopodium at a time. Amœbæ from the alimentary canals of higher animals may show one or many pseudopodia according to their condition. The search for food on the part of an amœba, as well as the desire for movement, entails the protrusion of several pseudopodia.

The pseudopodia vary greatly in shape. Two main types, however, can be distinguished. The first is broad and club-shaped, or lobose ; the second is long, narrow, and threadlike. It is usual for one type only to be produced at any one given time, though gradations between the two types necessarily occur.

The endoplasm is often very granular, and may include various non-living enclosures, such as crystalloid substance, waste material from food and colouring matter, as well as actual food particles themselves. The food is enclosed in thin films of liquid, and forms food vacuoles. The vacuoles contain some form of digestive ferment, and the amœba shows the most primitive form of digestion known. Further, in

* See p. 2.

order to ensure the adequate nourishment of every part of the cell, the food in process of digestion is made to circulate through the body of the amœba until finally, its power of yielding nourishment being exhausted, the body of the animal flows away from the débris and leaves it behind.

The actual food material varies considerably. The Amœbæ inhabiting water, mud, or moss seem to live almost entirely on minute forms of vegetable life such as algæ, though relatively large ciliates have been observed on some occasions in the bodies of the amœbæ of moss. Amœbæ inhabiting the human intestine vary again with respect to food. The nutrition alters according to the situation in which they are found. Those that are capable of penetrating deeply into the mucous membrane, and even into the submucosa, feed on the débris of the cells they invade, and some even ingest red blood-corpuscles. The forms occupying the alimentary canal are commonly termed *Entamæbæ*, and *Entamæba histolytica* and *E. tetragena* (most probably two forms of the same organism, though till recently believed to be quite distinct) have the power of devouring numerous red blood-corpuscles. Bacteria, and sometimes other Protozoa, are also seen in process of digestion within the cells. The *Entamæbæ* that are not pathogenic, though they are parasites of the alimentary canals of their hosts, do not seem to have the power of feeding upon the blood-elements.

All amœbæ possess a nucleus. The minute structure of the nucleus was a means by which species of amœbæ were defined, and was very im-

portant in connexion with pathogenic forms. Much of that importance has now vanished, for it has been shown by Darling that the appearance not only of the nucleus, but of the whole trophozoite, varies with the age of the parasite—that is, the nucleus has a cyclical structure. To make a general statement, the nucleus of an *Entamæba* is not very rich in chromatin, but the chromatin at one time forms somewhat irregular masses on the inside of the nuclear membrane, and is scattered as granules through the nucleus, while at another period in the existence of the organism most of the chromatin will be concentrated to form a central karyosome.

Excretion is a vital necessity for all living organisms. Two main systems of excretion occur among the amœbæ, and these systems can be roughly correlated with the mode of life of the particular amœbæ considered. Free-living forms, such as *Amœba proteus*, collect their liquid excretions into one part of the cytoplasm, forming a vesicle which has the power of rhythmic contraction. The vesicle gradually fills and becomes very obvious, under the microscope, to the observer. Then, suddenly, the contents are expelled, and the vesicle or contractile vacuole collapses and disappears from view. Other amœbæ have central reservoirs into which a number of subsidiary, radiating, collecting channels discharge. The mechanism of such excretory vacuoles is very suggestive of the closing of the iris diaphragm of a camera or microscope.

Yet another set of amœbæ, including the greater number of pathogenic forms, possess no general

excretory vacuole. As their absorptive processes need not be localized, so there is no necessity for the development of a special excretory apparatus. Just as the whole general surface is absorptive, so can it also be excretory. Formerly a broad statement was made that no pathogenic *Entamœba* possessed a contractile vacuole. While this is true for the *Entamœbæ* from the human intestine, yet it is not so universally, since *Entamœba chironomi*, that causes injury to the larvæ of *Chironomus* (the "bloodworms"), possesses a well-marked contractile vacuole with a radiating structure.

Increase of numbers among the Amœbæ takes two forms. The first consists simply of the separation of buds from the body of the trophozoite or the division of the trophozoite into two portions. Such methods are multiplicative, and serve to increase the number of parasites within the host. A budding phenomenon also occurs in degenerating and senile amœbæ. In order to effect the transference of the parasite to a new host, encystment occurs. The cysts are resistant, and within them, four, eight, or more spores occur. Sometimes the encystment is incompletely known, and the same is true of the schizogony of several of these amœbæ.

Entamœbæ are extremely important, as they occur commonly in the intestine of man in tropical countries, and they produce dysentery and diarrhœa. The Philippine Islands, for instance, were notorious for the number of deaths from dysentery until the United States made investigations into the cause. China, Japan, parts of India, tropical America,

Africa, and Egypt, as well as Italy and Greece (to name only a few places among the many affected), all have suffered from the prevalence of dysentery.

The various controversies that have raged around the causative agents of amœbic dysentery have tended to give the subject a general as well as a scientific interest. Lösch (1875) was one of the first to describe amœbæ occurring in dysentery, and to reproduce the disease by means of them. The first absolute separation of the pathogenic and non-pathogenic amœbæ from the human intestine was made by Schaudinn in 1903, who showed that in man there were at least two species of *Entamœba*. The one was relatively harmless, and occurred in healthy and diseased individuals alike; the second occurred only in unhealthy patients, and if its cysts were swallowed dysentery followed. The parasite of dysentery was named *Entamœba histolytica* by Schaudinn, and the companion but not disease-producing form was termed *E. coli*. Since Schaudinn's paper, quite a number of pathogenic species have been described, but many of these are now known to be stages in the life-histories of other amœbæ, so that one of the most indefatigable workers on the amœbæ of dysentery, Darling, now states that there is probably but one pathogenic amœba. In that opinion he is supported by several other eminent workers and former opponents. Most workers seem to be agreed that the greater number of cases of amœbic dysentery are due to one principal amœba. They now merely disagree as to the exact name whereby it shall be called, the rival names being *E. histolytica* and *E. tetragena*.

Of the two, *E. histolytica* has priority, and hence, probably, will persist, though the stages described by Viereck in 1907 as *E. tetragena* were undoubtedly the clue to the remarkable series of forms that constitute the life-cycle of the Entamœba.

Dealing first with the Amœbæ recorded from water, moss, and similar vegetable material, there is little to say, for they present the characters described for amœbæ generally. They possess remarkable powers of resisting desiccation, and when the pond or vegetation dries up, they encyst and remain thus until the return of more favourable conditions. The cyst at first possesses one large nucleus. This divides into two, and the daughter nuclei repeat the division until a number of nuclei are present. Cytoplasm collects round each of the nuclei, a cyst wall may or may not enclose each, and a collection of daughter amœbæ is thus produced. Sometimes the parent cyst wall crumbles down and the tiny daughter forms are liberated. At other times, on the return of moisture, the parent cyst wall breaks down and the daughter cysts pass out from it. The little amœbulæ, if within daughter cysts, escape from them in various ways, and can proceed at once to perform all the functions of their ancestors. Occasionally large amœbæ under adverse circumstances are said to depend for protection on the hardening of their outer layer.

The Amœbæ found in the bodies of animals are very numerous and have been recorded from almost all the larger groups of organisms. Those present in man are of most interest. They are not restricted

entirely to the intestine, but occur on the mucous membrane of the mouth, in carious teeth, in the lungs, the urinary tract, kidneys, liver, and genital tract. That certain intestinal amœbæ are non-pathogenic has already been mentioned, and such members perhaps are best described before the disease-producing forms.

Entamœba coli (Fig. 30) is a frequent occupant of both the healthy and diseased human intestine, more

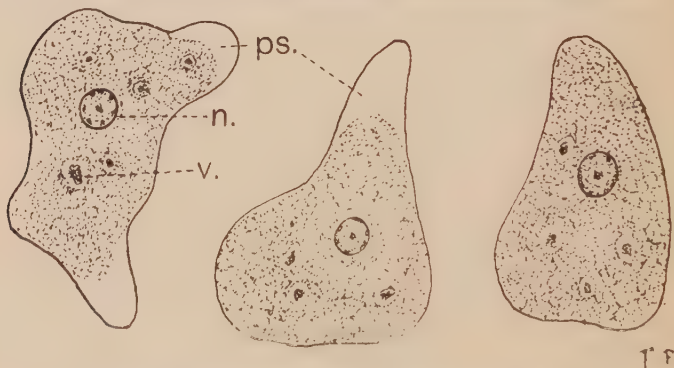


FIG. 30—THREE ASPECTS OF ENTAMŒBA COLI

n., Nucleus; *ps.*, pseudopodium, showing clear ectoplasm; *v.*, vacuole with food débris within

particularly in the tropics. It is therefore of importance, for amœbæ, when found in stools, may be indications that the person concerned is suffering from amœbic dysentery, or may merely indicate the presence of relatively harmless amœbæ in the bowel. *E. coli* occurs in the cavity of the large intestine, but it is usually incapable of penetrating the mucous membrane of the gut, for its pseudopodia are large and blunt.

E. coli is a medium-sized amœba, being 12 to 25 μ in diameter when it is quiescent. When moving, the amœba is fairly active, producing short, blunt pseudopodia (Fig. 30, *ps.*) with some rapidity. It has a peculiar greyish colour, and the round, vesicular nucleus (Fig. 30, *n.*) is clearly visible in life. The ectoplasm is best seen during movement, as the pseudopodia, when first formed, are entirely ectoplasmic. The endoplasm is compact, and as a rule vacuoles are absent or few, *E. coli* differing from some pathogenic amœbæ in this respect. Food débris (Fig. 30, *v.*) and bacteria occur in the endoplasm, but blood-corpuscles only occur there exceptionally. The parasite seems to avoid blood-corpuscles as food, and rarely, if ever, ingests them, even when supplied with them in abundance—another difference from the known pathogenic forms.

The multiplication of the Entamœba occurs usually by simple division into two daughter forms. The nucleus, which has a well-marked membrane and a central chromatin mass or karyosome, divides first into two, and then the cytoplasm follows. Rapid multiplication by schizogony also occurs. The schizont withdraws its pseudopodia and becomes roughly rounded. The nucleus increases in size, and divides by a process of multiple fission until there are eight daughter nuclei in the amœboid body. An eight-nucleate schizont is thus produced. Internally the cytoplasm collects around each nucleus, and the miniature amœbæ thus produced separate as eight merozoites.

Under unfavourable conditions encystment occurs.

All pseudopodia are withdrawn (Fig. 31, *A*, *B*) and food particles or excretory products are expelled from the body. A thin membrane then appears at the surface of the body and gradually increases in thickness. Within the cyst wall thus produced, the nucleus multiplies by a series of complicated divisions. During such division, some of the chromatin is absorbed, and such temporary dissociation of part of the chromatin and its subsequent reunion is considered by some to represent a form of conjugation, and is

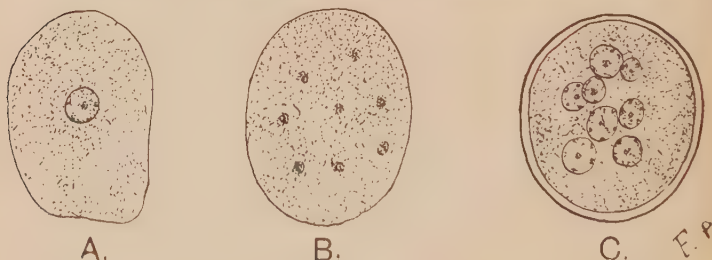


FIG. 31—*ENTAMOEBA COLI*: CYST FORMATION

A, Uninucleate form; *B*, showing formation of eight nuclei;
C, cyst with eight well-defined nuclei

termed autogamy. Eight nuclei are ultimately produced (Fig. 31, *C*), and within the parent cyst eight amœbulæ form. If either the parent cyst or the small daughter forms enter a new host with food or drink, the cyst wall is dissolved, the amœbulæ issue forth, and infection ensues.

Owing to the processes of binary fission, schizogony, and cyst-formation of *Entamoeba coli* there is a great diversity of forms encountered in fæces containing the parasite, and at any one stage the great

dissimilarity almost suggests different species, a fact emphasizing the need of prolonged observations.

Probably the most debated Entamœba of the last few years is *E. histolytica*, the main cause of amœbic dysentery. The organism was first described by Jürgens in 1902, while a memoir, in which the supposed life-cycle was minutely described, appeared by Schaudinn in the following year. Schaudinn also named the parasite, which probably had been notified even prior to Jürgens, though without special naming. *E. histolytica* has been examined since by several writers, and it may be stated that the life-cycle of the organism, as described by Schaudinn, is really but one portion of the development of the organism. Two other Entamœbæ, previously described as two different species, have now been proved to be part of the life-history of *E. histolytica*, instead of being distinct organisms.

E. histolytica, according to Schaudinn, is from 25 to 30 μ in diameter, though other observers state that it is much smaller, a result easily explainable from further knowledge. It has a sharply defined ectoplasm (Fig. 32, *a*) which it protrudes as pseudopodia (Fig. 32, *a*); these are spiny when it is burrowing into the wall of the intestine. The endoplasm is slightly granular and passes into the pseudopodia. Its nucleus varies in form and position, and is not easily seen in the living organism.

The enclosures in the cytoplasm are of interest. They include various crystalloid substances (Fig. 32, *e*), bacteria and red blood-corpuscles, on which the animal often feeds. Vacuoles (Fig. 32, *d*) are

present, but these do not contract as in the free-living forms, and a large number may be present. Should red blood-corpuscles (Fig. 32, *c*) be present in the *Entamoeba*, the action of the latter on them can be seen under the microscope so long as the organism is kept warm. The red corpuscles gradually break up, void their colouring matter, which then

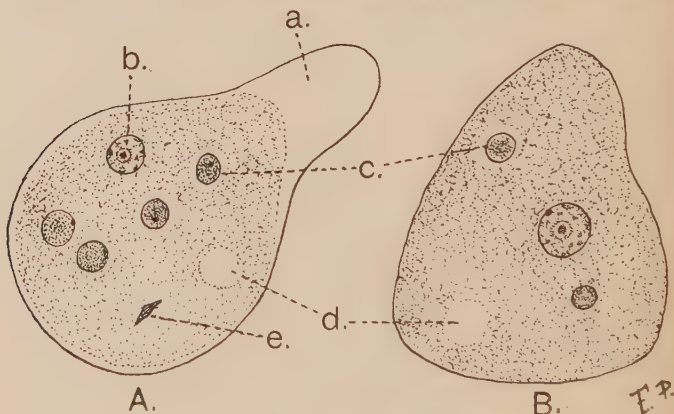


FIG. 32—*ENTAMOEBA HISTOLYTICA*

A, B, Two large trophozoites; *a*, pseudopodium of clear ectoplasm; *b*, nucleus of "tetragena" type; *c*, ingested red blood-corpuscles; *d*, vacuole; *e*, crystalloid substance

becomes somewhat greenish, and gradually disappear, till a "shell" or "ghost" is all that remains to show that they ever existed.

The methods of multiplication of *Entamoeba histolytica* used to be considered to be twofold. Simple division occurs just as in *E. coli*, and as in that organism, is initiated by the division of the nucleus into two equal or almost equal portions. Gemmation or multiplication by bud formation was

said to occur. The nucleus (Fig. 33, *A*) of the parent amœba was said to divide into a number of portions, which migrated into the cytoplasm. Each new nuclear portion was said to push outwards, along with a part of the cytoplasm (Fig. 33, *B*), and each

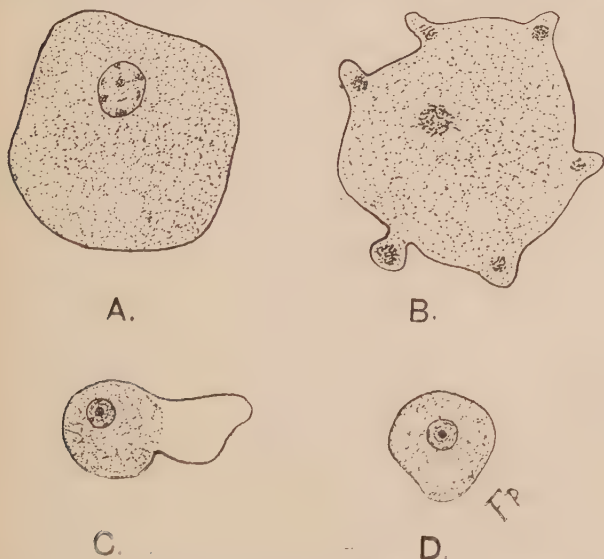


FIG. 33—*ENTAMŒBA HISTOLYTICA* : SENILE AND "MINUTA" FORMS

A, Uninucleate form ; *B*, senile form showing peripheral budding ; *C*, small type of dysenteric amœba formerly known as *E. minuta*, showing large pseudopodium and "tetragena" type of nucleus ; *D*, "minuta" form, as seen in the quiescent condition

part separated as a small bud. Now, however, this mode of peripheral budding is considered to occur only in old and degenerating *E. histolytica*.

Spore formation is to be regarded as the provision made by any organism for continuing its life under

unfavourable conditions, while the spore phase also serves as a resting or recuperative period for the organism concerned. *E. histolytica* also was thought to form spores, and the process strongly resembled that of gemmation, the main difference being that the spore surrounded itself with a thick, yellowish sporocyst, which readily resisted desiccation, and was believed to serve as the starting-point of a new infection after some time had elapsed. These supposed spores are small, about half the diameter of a red blood-corpuscle. Some workers believe that these remarkable, small spores are produced by old trophozoites, such as are found during convalescence and after apparent recovery of the victims of amœbic dysentery. On the other hand, many investigators consider that the so-called small spores of *E. histolytica* are of fungoid nature. The correct sporogony of *E. histolytica* must be sought in the cyst formation of the organism formerly known as *E. tetragena* (Viereck). Small forms of the latter have been described from dysenteric cases in South America by Elmassian, and called *E. minuta* (Fig. 33, C, D).

Viereck (1907) described an amœba from cases of dysentery, and named the organism *Entamœba tetragena*, as its outstanding feature was the formation of cysts containing four spores. It was the detailed study of *E. tetragena* that revealed that one organism only was responsible for the diseases referred to three different species of Entamœbæ, and that *E. histolytica*, *E. minuta*, and *E. tetragena* were different phases of one and the same vector of disease. The organism, until recently described as *E. tetragena*, and on which

one of the present authors has done much work, has a trophozoite from 20 to 30 μ in diameter, and it possesses both ectoplasm and endoplasm. The endoplasm is not intensely granular, but has the power of feeding upon red blood-corpuscles. The nucleus is large, round and possesses a karyosome, in which a central spot is seen sometimes (Fig. 32, *b*). The multiplication is by binary fission and also by schizogony. Some of the smaller amœbæ become four-nucleate by division, and each of these ultimately divides into four merozoites, which become separate small amœbæ. After a number of asexual generations, cyst formation commences. The amœba about to encyst withdraws its pseudopodia, becomes rounded, and ejects most waste products from its endoplasm. Nuclear changes follow this rounding, and division into two occurs. The division is repeated and a cyst with four nuclei is produced (Fig. 34). Each nucleus collects cytoplasm and ultimately four spores are formed. These cysts and spores are capable of producing heavy infection if swallowed by a new host.



FIG. 34—CYST OF ENTAMOEBA HISTOLYTICA, SHOWING THE "TETRAGENA" FORM WITH FOUR NUCLEI

Sometimes diseased or pathological specimens of the amœba itself can be found. These forms show abundant budding such as Schaudinn described for the spore formation of *Entamoeba histolytica*. They

appear towards the end of the life of the entamœba, and are now known to be buds produced by an exhausted trophozoite.

As before mentioned, small trophozoites producing small cysts have been described by Elmassian under the name of *E. minuta*. This organism multiplies by schizonts which form four daughter merozoites. They also pass from host to host as small cysts that give rise to four spores. Thus, apart from its smaller size, *E. minuta* is like *E. tetragena*.

E. histolytica, *E. tetragena*, and *E. minuta*—how do they form one complete life-cycle and not three life-cycles? The first step in the matter was taken by Fantham (April, 1911), who pointed out the need for the consideration of the great polymorphism shown by Entamœbæ, and stated that “probably *E. minuta* is merely a variety of *E. tetragena*.” Subsequent work has proved the truth of this suggestion. Darling more particularly has worked on the subject, and by experiments with kittens has shown that by successive passages from host to host it is possible to produce any known form corresponding to *E. histolytica*, *E. tetragena*, or *E. minuta*. Commencing with the large trophozoites with a nucleus poor in chromatin, once said to be characteristic of *E. histolytica*, he showed by experiments that the character of the nucleus gradually changed until it showed the large quantity of chromatin and prominent karyosome identified with *E. tetragena*. The different sizes in the cysts and the production of small generations was shown to depend on the nearness or remoteness of the encystment period to that

of division, and to the variation in the number of divisions undergone by the organism prior to its assumption of the resting form. *E. minuta* thus originated. Finally the budding phenomena described by Schaudinn were traced and found to be of a degenerative nature.

What, then, should be the proper title of the organism around which so much discussion has raged? On the score of priority, the name *E. histolytica* supersedes that of *E. tetragena* and *E. minuta*—a course that is regrettable, since it was from laborious researches on *E. tetragena* that the life-cycle was elaborated, and some of the great confusion regarding the pathogenic Entamœbæ of man was removed.

Another amœba associated with dysentery in Japanese has been named *E. nipponica*. It was found together with *E. histolytica*, and, like it, is capable of devouring red blood-corpuscles, which are found within it. The nucleus contains a karyosome, and so is like the “tetragena” form of *E. histolytica*. Multiplication is by division into two, or repeated division of the nucleus into six or eight can take place, so that six or eight merozoites are ultimately formed. Prior to encystment some of the chromatin is expelled from the nucleus into the cytoplasm. Darling considers that *E. nipponica* is a form of *E. histolytica* (*E. tetragena*). A recent paper by Akashi suggests that *E. nipponica* is not a true parasite, but that epithelial cells were mistaken for amœbæ in such cases.

Other Amœbæ from the alimentary canal of man

have been described from time to time. Probably one of importance will be found to be *Noc's Entamœba*. This was first found as cysts from liver abscess and in dysenteric stools, and also in the water-supply of Saigon, Cochin China, and is now known to occur in many parts of India. It is probably a variety of *E. histolytica*, which it resembles in its polymorphism and in its schizogony, being said to form many merozoites.

The spread of *Entamœbæ* to man seems to take place almost entirely by means of contaminated water and raw vegetable food such as salads. Water should always be boiled, and if there is a suspicion of dysentery in a tropical district, abstention from salads, etc., is most desirable, since they are easily made infective by the ordinary agricultural process of manuring land.

CHAPTER VIII

YELLOW FEVER

AMONG the necessities of modern civilization, gold, rubber, and oil stand out pre-eminently, and each is associated, at any rate in South America and Africa, with countless tragedies and innumerable deaths. West Africa, fertile and productive almost beyond imagination, has long held the sinister and ghastly title of "The White Man's Grave," and though it is far from being the death-trap that it was thirty years ago, yet it is still true that workers there are subject to many dangers and diseases, little known or appreciated at home. Nor is West Africa unique in combining productiveness and death. "Yellow Jack" has been the dreaded foe of the Latin Americas, the South-East American Atlantic seaboard, and the West Indies, for more than three centuries; nor has it been unknown in the European ports associated by commerce with those countries, for the coast towns of Spain, more particularly, have suffered from outbreaks from time to time in the past.

Even in England outbreaks have occurred, though these have been confined chiefly to the ships containing the insect known as *Stegomyia fasciata*, which

carries the virus of the disease. When the decay of the trading powers of the southern European nations set in, the trade routes gradually crept northwards, and the west coast of France, Belgium, and Holland, and the German and English ports, particularly of the south and west, took over the commerce formerly restricted to the Mediterranean. It was then that the cases of yellow fever that have visited England were chiefly notified.

The original home of yellow fever seems to have been the islands of the West Indies, as many of the early explorers found to their cost. Even as early as 1495 the malady is supposed to have attacked the men under Christopher Columbus, and was carried by the Spaniards to the mainland. To-day the Eastern Atlantic coast in the tropical zones is the chief home of yellow fever. The mouths of the Amazon and Orinoco, the coast of Central America, Mexico, and parts of the United States bordering on the Gulf of Mexico, together with the West Indies, seem to form the principal centre of the disease. West Africa has a bad reputation, but there is some evidence that yellow fever was carried by ships to the Cape Verde Islands in the early years of the sixteenth century, and was spread to the Gulf of Benin from there about 1520. Now it is perhaps to be considered as a second centre, in which serious outbreaks have occurred in the past and where it is likely that some cases are always present.

Many British interests are bound up in West Africa, and British trade is constantly increasing there. Its great natural resources provide not only

gold, mercury, tin, and lead, but also great supplies of rubber, coconuts, copra, and numerous nuts from which oils are extracted on the spot. The latter are a very valuable production, and the majority of this British-produced commodity, vegetable oil, is utilized in the manufacture of artificial butters, oils and soaps in England. But even in these days of more definite sanitation, England loses many lives in her West African possessions through yellow fever, sleeping sickness, and malaria.

The early history of the association of England and yellow fever dates back to the adventurous times of exploration in the sixteenth century (though it is doubtful if epidemics actually occurred in England itself) and was continued in the seventeenth century, when the slave-trade became a regular and unhallowed feature of English commerce. The wooden ships of those times carried not only the unfortunate slaves, but numbers of deadly insects, with the result that not only did many slaves succumb on the journey, but the crews at times became so reduced in numbers that there were not enough men left to take the ships home. When land was reached, whether England or the Continent, outbreaks of the malady we now call "yellow fever" occurred, and it has been justly said that yellow fever was the price which Europe paid for the slave-trade.

Workers in the Southern States of America, in the West Indies, the Latin Americas, and on the West Coast of Africa, often suffer from what is euphemistically called an "acclimatizing fever," which results either in recovery or rapid death. This

fever is but a mild form of "yellow jack," and needs the same consideration. Biliary fever, bilious remittent fever, and pernicious remittent fever all have been used to cloak the name of the fatal malady known to early medical colonial history as the "Bulim fever," the "fever of Fernando Po," and "the fever of the Bight of Benin."

Disease is said proverbially to follow trade routes, and the opening up of communication with the interior of a country has a like result. Such is true of yellow fever, and the best example probably is afforded by West Africa, where the malady has been reported from practically every town along the coast and is now known in the interior along the courses of the Senegal and the Niger, though in but few cases. The Senegal cases practically follow the railroad and the trade routes. The most thickly populated area of West Africa is Sierra Leone, and the Gold Coast is next to it in population so far as the coast strip is concerned. Many attempts have been made in Africa to fix the responsibility for the spread of yellow fever on one or other of these places. Probably no one place is really responsible; it is more likely that the whole coast from Senegal to the Cameroons is equally involved.

There is one remarkable fact about yellow fever which is in strong contrast with many tropical diseases. The parasite of malaria was known long before its carrier. The organism *Trypanosoma gambiense* was known in some detail before *Glossina palpalis* was incriminated. The Kala-azar Protozoön is well known, while its carrier is still not perfectly demon-

strated. But with yellow fever the carrier is well known to be a common mosquito of the tropics, *Stegomyia fasciata*, while the infective organism can hardly be said to be demonstrated with certainty. Dr. Seidelin, working at Merida in Yucatan four years ago, found certain bodies in the blood of yellow fever patients. He believes these to be Protozoa responsible for the disease. Other workers have not found these bodies in yellow fever patients on the one hand, or on the other they have found similar bodies in cases of other complaints. More work is necessary before the exact nature of the agent of disease is determined, and some is now in progress in Africa.

What is the nature of the carrier? How does it live? How can it be destroyed? The answers to these three questions, put into practice, have stamped out yellow fever in many places, and have considerably reduced it in others.

Stegomyia fasciata, also called *S. calopus*, is a small mosquito about $\frac{1}{8}$ to $\frac{1}{5}$ inch long. It appears grey in colour when on the wing, and floats from one place to another like a "bit of fluff." Its thorax possesses two silvery, curved, lateral lines, with two parallel yellow lines between them. The abdomen is dark, with white bands. Its third pair of legs are banded with white, and when the insect alights, it waves these legs up and down. The popular names of the "tiger mosquito" and of the "Scots Grey" have been given to it on account of its markings. The *Stegomyia* is essentially a house-haunting mosquito, and it is also a water-breeder, utilizing extremely

small quantities of water in which to lay its eggs, and seven batches of eggs are laid successively. It moves practically noiselessly, and bites by day as well as by night, but is more or less quiescent between 9 a.m. and 3 p.m. When a mosquito has bitten a yellow fever patient, the virus needs twelve to thirteen days in order to mature in the body of the insect and to acquire its full virulence, and, once infected, there is no evidence that it does not remain infective for life. Further, the mosquito must bite the patient during the first three or four days of the illness in order to become infective.

The *Stegomyia* has been mentioned as frequenting houses. It selects cool, quiet, dark spots for egg-laying, and does not seem as a rule to fly long distances. It seeks cover as soon as hatched, and is able not only to enter houses, but to penetrate ships lying at anchor in the river or off the town. Thus it happens to be the most common mosquito aboard ships, and can remain concealed for long periods. Egg-laying is preceded as a rule by a meal of blood, human for preference. In Nature this invariably occurs, and though *Stegomyia* in captivity have been trained to live on plant juices, their ovulation was greatly delayed and unsuccessful. The ova are very small, but rapidly develop into "wigglers" or "wiggle-waggles," and it is astonishing how little water is needed for their vigorous development. In tropical towns it is wonderful how many unsuspected breeding-grounds for larvæ exist. In African fishing villages, or where canoes are numerous, the rain-water that collects in the boats teems

with *Stegomyia* larvæ. British Honduras exports much logwood, and the water that collects in the depressions of the logs on the wharves, though purplish-black and highly astringent, contains larvæ in large numbers. Large water-vats are in common use in Central and South America. They furnish favourite breeding-grounds. Some West Indians endeavour to protect their flower-beds from the attentions of the umbrella ants, and the little ditches used for this purpose do far more harm than good. The ants may be circumvented, but a plague of mosquitoes replaces them. Rot holes in trees, water holding epiphytes, inverted bottles (used for borders in some parts of Africa), roof gutters, and, above all, discarded bottles, crockery, and tins of all sorts provide innumerable opportunities for the breeding of mosquitoes. Immense numbers of cans, used for tinned food, are found in districts in West Africa opening up to commerce, and as Sir Rubert Boyce wrote: "A veritable tin-can invasion extends up from the coast towns into the interior villages. The more traders the more tin cans." In other countries, also, the same thing is observed. The water-holding capacity of these discarded utensils is enormous, and, to complicate matters, they are not always obvious, being concealed in the weeds and low bush immediately about the houses and in the compounds. Protected by the foliage from the sun, and easily filled by rain showers or by drippings from the foliage, they are ideal for the mosquitoes, which breed there freely. Thus it is seen that the breeding-places of the *Stegomyia* are artificial to an enormous extent,

and the domestic water-supply, supplemented by water in the rejected household "odds and ends," becomes of great importance in propagating disease.

Why should so much importance be attached to *Stegomyia fasciata*, which is but one of many tropical mosquitoes? The answer is twofold: Wherever this particular mosquito abounds, "yellow jack" may possibly occur. Where the fly is absent, the disease is absent. But though yellow fever had been known for a long time, it was not till the end of the eighteenth century that the association of the mosquito with the disease was suspected. Then several investigators in America drew attention to the fact that numbers of mosquitoes were present during the epidemics that visited various districts. Towards the end of the nineteenth century attention was drawn again to the fact that the incidence of yellow fever coincided with the appearance of the mosquitoes, and that when cold weather came and killed the insects, the human malady also disappeared. In 1878 an epidemic at Mobile was controlled by anti-mosquito measures. In 1881, Finlay again emphasized his idea that yellow fever was mosquito borne. In 1882 the case was clinched, for Dr. Gerard allowed a mosquito that had fed on a fourth day yellow fever patient to bite his hand, and in consequence he had an attack of yellow fever. The final proof of the transmission of the disease by the mosquito, *S. fasciata*, was made by Reed, Carroll, Agramonte, and Lazear, and the seal was set on the mosquito, for the information was gained by the death of one of the heroic experimenters (Dr. Lazear) from yellow fever, following the bite of

the insect. Knowingly, and deliberately, these American investigators in Cuba allowed *Stegomyia* that had fed on yellow fever patients to bite them. They observed closely all that followed in their own cases until unconsciousness prevented further observations, and the sacrifice of life itself proved the point at issue, and opened the way for the salvation of the enfevered parts of the world.

What does *S. fasciata* carry and transfer to man? That, as before indicated, is a moot point. Until four years ago few indications of a parasite had been found; the virus was able to pass through a filter, and hence anything present must be extraordinarily minute. Dr. Seidelin has found certain bodies both in the blood-corpuscles and in the tissues of yellow fever patients. The structures are very minute. They have ringlike, oval, or sometimes irregular forms, and seem to consist of a small amount of cytoplasm with a little deep-staining (nuclear) material, judging from stained specimens. The bodies in question somewhat resemble very young malarial parasites and the organism, *Theileria parva*, of East Coast fever in cattle. They are smaller than *Babesia* (see Chapter IX.).

Although yellow fever in its acute form is recognized with a considerable amount of certainty, yet at its commencement, as with most disorders, there are few symptoms. Chill and cold, with headache, are usual. Pains in the back and limbs may be present. The temperature rises for twenty-four to forty-eight hours, and may even reach 105° F., and this continues for four to five days, the pulse also

increasing with it. Then the pulse slows considerably. The first definite sign is the occurrence of vomiting, the vomit being speckled with dark or black patches. This gradually assumes the characteristic form known as black vomit, when the ejected substance is said to be like coffee grounds. The kidneys are intensely affected, and much albumin at first appears in the urine; then the latter diminishes and may be entirely suppressed. Yellow coloration of the eyes and skin appears, though this may be late in the disease.

After an acute stage an improvement occurs, and the patient feels well, and wants to get up and to take food. Both are fatal. A relapse follows rapidly, and insensibility gives place to death. The period of "feeling well" is absolutely the most dangerous of all, and needs most attention. With regard to remedies or treatment, everything depends on good nursing. There must be absolute rest of every part of the body, no food should be taken, but as much alkaline water (*e.g.*, Vichy water) as the patient cares for must be given. If the water cannot be taken, saline injections are necessary. No sitting up of any sort or for any purpose must be allowed. The heart's action can be stimulated with drugs such as digitalis, strychnia, or alcohol. Small quantities only should be given, and champagne is the best form of alcohol to use. In addition, the patient must be most carefully screened from all mosquito-bites. This is as much for the benefit of others as for himself, as the virus is infective in the patient for the first three days. If, moreover, the *Stegomyia* obtains blood during these

three days, the virus incubates in its body for about twelve days, and at the end of this time the mosquito is most heavily infective, and its bite produces acute disease. Needless to say, strict regard must be given to cleanliness and the maintenance of quiet in and about the sick-room. Food should not be allowed until the temperature has been normal for a day or two, and when the kidney action has been re-established. Complications are uncommon, and the patient usually recovers completely, and has acquired a more or less persistent immunity.

In many tropical places it has been stated that there is a periodicity in the appearance of yellow fever. In some parts of Africa, the natives believe in a seven-yearly outbreak, while in Barbadoes the period is cited as thirteen years. Investigation shows that there is no such periodicity. Outbreaks occur in the tropics after the rainy season, since with much water in all sorts of receptacles the *Stegomyia* have endless chances of breeding. Cold makes mosquitoes torpid and retards egg-laying; consequently, "frost puts an end to an epidemic."

Certain races have been stated to be immune to yellow fever. Negroes undergo slight, scarcely recognizable attacks when young, and acquire immunity. In an epidemic, the non-immune whites succumb, while as a rule the blacks are not much affected. These immune races are, then, in the position of virus carriers. Themselves infected, they feel no ill-results, but the *Stegomyia* can obtain the virus from them and transfer it to non-immune people. Europeans born in yellow fever centres

acquire immunity if they survive childhood, but both they and the native races lose their immunity when away from the centre of infection, and are susceptible to it on their return.

The main remedy for yellow fever, then, seems to be a campaign for greater sanitation and for mosquito destruction on a systematic scale. Destruction of the carrier is easily accomplished by putting paraffin or petroleum into pools, etc., where the larvæ are found. Breeding can be stopped by the removal of water from superfluous vessels of all sorts, by screening the entire household water-supply, and by proper clearance of bush, etc., around compounds. The separation of the dwellings of Europeans and natives is very sound policy. By these means, the enormous wealth of tropical countries can be obtained with fewer of the tragedies that have hitherto marked the progress of white men and civilization in the tropical world.

CHAPTER IX

SOME CATTLE DISEASES—REDWATER AND COAST FEVER

FROM earliest times, and among the most primitive peoples, cattle have formed a basis of wealth. Abundance of flocks and herds was the ideal of pastoral peoples, and in later days, of the agricultural population who form the backbone of any nation. England may be described as a favoured country with respect to its cattle-rearing. There is no rinderpest to kill off the herds as in South Africa, and no tsetse flies to destroy cattle and horses alike by carrying trypanosomiasis, while the ticks that cause enormous losses of cattle in America, Australia, and some parts of Africa and Europe, by producing "redwater" in these animals, are uncommon, and as a rule uninfected even if present.

"Redwater" is due to small blood-parasites that live in the red corpuscles, and cattle, sheep, horses, dogs, as well as smaller animals like jackals and rats, may be infected. The parasites destroy the red blood-corpuscles, and the excreted colouring matter from them produces the "redwater."

The disease of most importance economically is

that known as cattle piroplasmosis, this name being given to the malady because it is due to the action of small pear-shaped organisms inhabiting the red blood-corpuscles of the host, in which bodies growth and multiplication of the parasite occurs. The organism is often known as a *Piroplasma*. Cattle piroplasmosis is variously known, as "redwater," "redwater fever," and "Texas fever," but it is distributed in cattle practically throughout the world, though most virulent in the tropical and sub-tropical countries. In North America great losses of cattle occur in certain districts in Canada, but these are slight compared with the condition of affairs in the United States, where it is estimated that the monetary loss due to deaths of cattle from piroplasmosis may amount to £8,500,000 yearly. In Queensland the loss is also extremely severe, but is rather on the decrease than on the increase. New South Wales and Victoria also suffer. Considering that 50 per cent. of the meat consumed in England comes from America and Australia, and that both of these countries are increasing their home consumption, the shortage due to disease cannot help but have a deleterious effect on England, especially when combined with a decline in home production. Practically £4,000,000 worth of imported living oxen, cows, and calves are slaughtered for food in England each year, while £14,000,000 per annum is spent on food imported as dead cattle. £10,000,000 is expended annually on "fresh" (or refrigerated) mutton, and it may be mentioned that piroplasmosis affects sheep badly as well as cattle. The national

food bill for imported butter is £24,000,000, while cheese accounts for £7,250,000. When, then, epidemics exterminate a quarter of the cattle in an exporting country, the monetary loss to that country is serious, and the importing country likewise suffers, owing to the rise in cost of living. Again, the home supply is in some slight danger from "redwater," and the writers have personal knowledge of losses of milch cows and calves from attacks of piroplasmosis both in the West of England and in Ireland. We have also experience of "redwater" in French cattle, though this is of a somewhat mild type.

It should here be mentioned that the names *Piroplasma* for the organism and piroplasmosis for the malady are very commonly used, but that, strictly, *Babesia* is the name of the Protozoön, and babesiasis that of the complaint. Any reference to recent literature involves knowledge of both sets of names. *Babesia bovis* is the name of the cattle parasite.

Draught animals such as horses, mules, and donkeys are considerably affected in some countries, especially in South Africa, and the disease there is known as biliary fever. Two different parasites occur in two separate, but often confused, maladies of horses, and this also happens in certain cattle diseases.

The organism causing the death of horses in Russia and Caucasia is different from the one whose fatal effects prevent horse traffic in various districts in South Africa.

India suffers, too, from piroplasmosis of cattle, and the *Babesia*, which, perhaps has been the most

studied of all, occurs there, in *Babesia canis*, which produces malignant jaundice in dogs. The same disease occurs in South Africa, and in both cases usually entails loss of valuable animals imported either for the stud or for hunting, bitches being more commonly used for the latter purpose.

Nearly allied to the Piroplasmata are smaller blood-



FIG. 35.—*BABESIA BOVIS* IN THE BLOOD OF A COW: RED CORPUSCLES REPRESENTED DIAGRAMMATICALLY

A, B, Pear-shaped parasites showing nucleus, so-called blepharoplast, and loose mass of chromatin; C, D, E, pyriform parasites at different stages of direct division; F, ovoid form

parasites causing fatal diseases among cattle, particularly in East Africa. The organisms are known under the name of *Theileria parva*, and "Coast fever" is the dread of the farmer in the country. We may next consider some of these parasites.

The parasite concerned with "Texas fever" or "redwater" of cattle is a small oval or pear-shaped organism (Fig. 35) living within the red cells of the blood. Some of these pearlike or pyriform bodies become free in the blood-stream, but after a short time, they approach new and uninfected red corpuscles, moving with their blunt end first. They press themselves against the walls of the blood-corpuscles, which become indented. Little by little the parasites disappear from view, and when completely inside, the outlines of the corpuscles are restored. Each parasite grows a little, and then becomes ready for multiplication. At this time it is pear-shaped (Fig. 35, *A*, *B*), and contains a dense mass of chromatin forming the nucleus, occasionally a so-called blepharoplast, and a loose mass of chromatin. The parasite next becomes rounded, and then amœboid, when it wanders actively about the interior of the blood-corpuscle. After this motile period it again becomes rounded (Fig. 36, *A*), and then protrudes two bud-like processes (Fig. 36, *B*), which grow rapidly, and ultimately form two pear-shaped masses (Fig. 36, *C*) attached together by the shrunken remains of their parent.

When the parasite becomes rounded, the two chromatin masses mentioned above gradually unite, only to divide again into a Y-shaped mass. Each of the arms of the Y gradually extends into one of the buds (Fig. 36, *B*, *C*), which are still connected, and this peculiar method of division is often termed gemmation and chromatin forking. Finally, the thin strand that connects the two pyriform buds breaks,

and the two individuals are thus separated (Fig. 36, *D*). Then, as a rule they either force their way out or the corpuscle bursts and liberates them into the blood-stream, where they at once enter other corpuscles and recommence their cycle. Occasionally, division of the daughter forms recommences in the same host

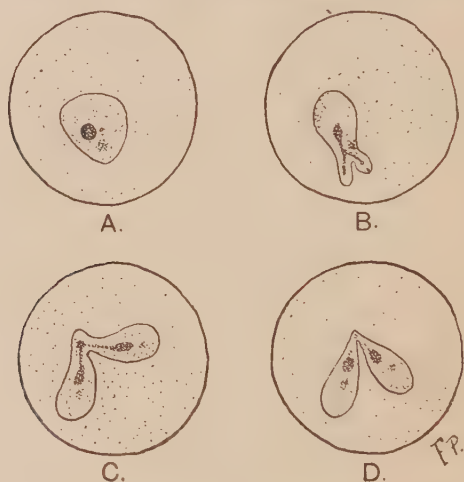


FIG. 36—DIVISION OF *BABESIA BOVIS* BY CHROMATIN FORKING

A, Form about to divide; *B*, two small buds formed, chromatin Y-shaped; *C*, more advanced stage; *D*, daughter forms about to separate

cell, and consequently four, six, eight, and more parasites occur within one corpuscle. It is rare for two parasites to invade the same host cell, though it has been known. Another interesting feature is that one amœboid parasite may divide into two, and then each of the two give rise to two pyriform organisms. Should rounded or imperfectly divided

forms escape into the blood-plasma, as a rule they merely degenerate.

While division by chromatin forking is characteristic of the *Babesia*, it is not universal. Experience has now shown that the organisms can divide into two without the necessity for the somewhat complicated chromatin forking. The nucleus simply constricts into two, as in other Protozoa, the halves separate, and the protoplasm follows the nuclear division (Fig. 35, C-E). This has been seen in the redwater parasite of Australia, in some English cattle, and in the *Babesia* of the white rat. Briefly stated, chromatin forking is common, but not universal.

The Protozoön responsible for Coast fever in cattle presents considerable differences from that of redwater. In the first place, not only does it infect the red blood-corpuscles, but the leucocytes and the glands may be infected. Gonder considers that the multiplication is at its height in the glands, and that it is uncommon in the peripheral blood. Having had personal experience of the parasite (*Theileria parva*), we can confirm the latter statement.

The organism is very small and most difficult of observation. It is also abnormally active, and can change its place sometimes five or six times within a minute, and executes a most irregular course through the interior of the blood-corpuscle, a map of its course somewhat resembling that produced by superimposing several broken spider's webs. The commonest forms seen in the blood are rodlike (Fig. 37, D-F), club-shaped (Fig. 37, C), comma-like,

and ovoid bodies (Fig. 37, *A*). Pyriform parasites (Fig. 37, *B*) are not common. Irregular forms also occur.

Division is of the simple type (Fig. 37, *E*) and is performed within the internal organs and especially in the glands. Investigation in England has shown



FIG. 37—*THEILERIA PARVA* FROM THE BLOOD OF A COW: BLOOD-CORPUSCLES REPRESENTED DIAGRAMMATICALLY

A, Ovoid form of parasite with chromatin at one end; *B*, pyriform parasite; *C*, club-shaped forms; *D*, rodlike organisms, one with two chromatin masses; *E*, corpuscle containing several parasites, two of which have chromatin caps showing apparent division; *F*, corpuscle containing six different forms of *T. parva*

a remarkable constancy in the numbers of the parasites in different organs of the cow, and of similar relations between the different forms of parasites found at one time. Infected blood-cells containing four or more parasites (Fig. 37, *E*, *F*)

were by no means rare, but there was no way of telling whether the numbers were due to multiplication of the organism within the corpuscle, or were the result of multiple infection.

The various Piroplasmata (genus *Babesia*) are essentially parasites dwelling within the red corpuscles of their hosts. What effects have they upon the animals harbouring them? The red corpuscles of the blood contain hæmoglobin, a substance capable of absorbing oxygen and of transporting it to the tissues of the body. When *Babesia* occur in the blood, the numbers of red blood-corpuscles may become only about two-thirds the ordinary number, the others having burst. The number of blood-elements being thus reduced, the blood becomes very anæmic and watery, and the animals are much weakened. The blood-pigment, hæmoglobin, is set free by the bursting of the corpuscles, and is often excreted by the kidneys, thus giving the name "redwater" to the disease. Besides alterations in the corpuscles, bile-pigment occurs in the blood-serum, accounting for the marked jaundice seen, for instance, in dogs. Enlargement of the spleen is common both in cows, horses, and dogs, at any rate in the tropics. A loss of weight always occurs and leads to great emaciation in chronic cases. Death is the usual result, though some animals acquire a partial immunity, when they habitually harbour a few parasites in their blood without being adversely affected thereby. They then are even more dangerous than obviously sick animals, since they act as reservoirs of the disease.

In contrast with piroplasmosis, Coast fever in cattle, due to *Theileria parva*, is not characterized by "redwater," nor can the disease be experimentally communicated by the inoculation of infected blood. On relatively few occasions, animals recover from attacks of Coast fever. When this occurs, the cattle are incapable of infecting ticks that may feed upon them, and thus do not spread the disease. Cattle which are immune to piroplasmosis are susceptible to East Coast fever.

The method of infection of cattle and dogs in Nature assumes great importance, for success in combating these fevers lies in destroying the intermediaries. Cattle, horses, and dogs all become infected by the agency of ticks which have previously fed on infected animals, or have been born infected.

The redwater of cattle is transmitted chiefly by *Boöphilus annulatus*, *B. australis*, *B. decoloratus*, and *Ixodes ricinus*. Other ticks transmit it occasionally, while still more are under grave suspicion. Coast fever is due to the attacks of *Rhipicephalus appendiculatus* and *R. simus*. Sheep infested by *R. bursa* die of redwater. Canine piroplasmosis is transmitted by *Hæmaphysalis leachi* in South Africa, and by *R. sanguineus* in India, where the former tick is unknown. The biliary fevers, fatal to horses, are passed from horse to horse by the bites of the ticks, *Rhipicephalus evertsi* and *Dermacentor reticulatus*.

In order to understand the remarkable way in which outbreaks occur, it is necessary to know the life-histories of the transmitting ticks. *Boöphilus annulatus* is one of the most destructive to cattle, and its life-

cycle may be considered. The order of events is as follows : Both sexes of ticks are found on the same cow, the male being very small and the female very large and gorged heavily with blood. After mating, the female drops to the ground and proceeds to lay her eggs. In the case of the cattle tick, the ovaries of the mother are infected by the *Babesia*, and when the young develop within the egg, the parasites gain entry into their organs, so that the young tick is born infected. After a time, varying with the weather conditions, the larva hatches out. It is a small, remarkably active, six-legged animal, and rapidly makes its way up the neighbouring vegetation as high as it can, and remains there until the advent of cattle gives it an opportunity to reach a host. As the cattle push through the vegetation, the larvæ leave the plants with great agility, fasten their mouth parts into their hosts, and proceed to gorge themselves. On the same host the larvæ moult and become nymphs, and after a further moult the adult forms are assumed.

The sheep tick, *Rhipicephalus bursa*, feeds on the same host as larva and nymph, and moults once upon the sheep. The nymph falls off when fully gorged, undergoes metamorphosis upon the ground, and then attacks a second host. The larvæ of *R. bursa* do not seem to be infective, but the adults are.

Supposing the cattle tick, *Ixodes ricinus*, is the one concerned, from hatching to larva the sequence of events is like that in *Boöphilus*, but when the larvæ are fully distended with blood, they drop from

their first hosts to the ground, and remain practically motionless until they moult. Meanwhile the first hosts of the larvæ pass on. When the larvæ have moulted they become nymphs, and possess eight legs instead of six. Once again they climb the foliage near them and await victims. Again they obtain a meal from their hosts, and in return, infect them. A further wait on the ground to which they have dropped leads to a second moult, and the fully mature ticks emerge, to await a final victim, from which they obtain a meal, on which they mate, and which they may infect while feeding. *Ixodes ricinus* thus needs three hosts in order to complete its own development.

The disease appears in cattle about nine to twelve days from the time when they were bitten by the infected ticks. The larvæ of *Boöphilus* are infective as well as the adults. The tick *Ixodes ricinus*, that carries European redwater, is interesting, as the larvæ from the eggs of an infected mother are already infected and can infect cattle at their first meal. The dog ticks responsible for the spread of *Babesia canis*, do not appear to have acquired complete hereditary infection. Neither the larvæ of *R. sanguineus*, the common dog tick of India, nor of *Hæmaphysalis leachi*, which is the carrier of piroplasmosis in South Africa, seem to transmit frequently as larvæ; but if the said larvæ have fed on infected dogs, they can carry over the disease when they become nymphs and also as adults.

The problem of what happens to the parasite when within the tick is still incompletely solved.

Christophers has given an account of some stages in the development of the dog piroplasm in the tick, *R. sanguineus*, but there are still some gaps, and few observers have been able to follow all that has been described. In the egg the piroplasms become more or less rounded and penetrate the cells of the developing embryo. In some parts of the body no development seems to occur, but in the salivary glands Christophers states that the parasites break up into swarms of smaller forms, which he terms sporozoites, and these minute bodies are injected with the salivary fluid when a wound is made by the bite of the tick.

The treatment both of piroplasmosis and of Coast fever at the present time is somewhat unsatisfactory. Nuttall and Hadwen, by injecting a 1 to 1½ per cent. solution of trypan blue intravenously, cured dogs infected artificially with piroplasmosis in England, and it was hoped that the use of this drug might stop the great mortality among cattle. Up to the present, in Queensland and America, when the drug has been tried for cattle, it has been found of some service, but dogs in India, even though treated with the greatest care, have often died without any improvement. Recently the writers were in communication with a large stockbreeder of South Africa, and this gentleman informed us that no doubt the trypan blue was of some use, but that the meat was unsaleable even a year and a half after the use of the drug, owing to the staining effect of the trypan blue. The drug appears to be most useful in mild or chronic cases of piroplasmosis. In acute cases,

which have been successfully treated, the recovered animals become "salted"—in other words, they still harbour a few parasites in their blood. The treatment of cattle is, then, of service in obtaining "salted" animals, which will resist re-infection when taken into infected areas. Patton, in India, has cured a piroplasmosis among the hunt-dogs of Madras by salvarsan, but it has not yet been applied to domestic animals.

Preventive measures should be considered. These, while troublesome, have been effective when well carried out. Dips of many varieties are of use for spraying sheep or cattle, or literally "dipping" them, but success is only partial, as ticks around the head and in the ears are not attacked, while others are rendered only partially insensible. The use of dips, followed by hand-picking, is of service in cases where the numbers of cattle are limited. But the animals in these cases must be kept off the pasture, for larval and nymphal ticks in varying degrees of infectivity may be there. In America it has been found that absence of cattle from infected pastures for a few months causes the death of young ticks by starvation. Should older ones be present, they may remain alive for some time without feeding. The use of gas-lime on pastures is certainly somewhat of a deterrent, but burning the pasture appears to be the most efficacious means of clearing the tick pest.

The movement of cattle from tick-infested to tick-free areas must be under strict control. In South Africa a huge "tick belt" stretches across the

country, and only tick-free cattle may pass beyond it. Rigorous inspection along the barrier is observed, and the spread of the ticks into the clear areas thus prevented. In America, quarantine of cattle is enforced prior to removal. Spring brings a renewal of activity of the ticks as well as of most other animals. The cattle are quarantined for some days until the majority of the ticks have dropped from them. They are again detained in new enclosures should any ticks be found, and the quarantine is repeated until they are perfectly tick-free. They then are grazed on pastures that have been unused for at least one year. Low temperature is bad for *Boöphilus*, and the larvæ die at a temperature of about -8° C. Winter conditions are a great aid to the United States in combating ticks and tick diseases. But when a country like Queensland or South Africa is concerned, where winter conditions differ but little from summer ones, and both have a high temperature, quarantine methods are far less effective, since there is no cold to kill the larvæ.

In Russia and other European districts where cattle ticks abounded, redwater is said to have disappeared with drainage. This is explained by the dryness causing the death of the larval ticks. A similar result is stated to have occurred in Queensland when certain swamps were drained. But while drainage has undoubtedly been of use in some cases, it has not in others, and we know of one ironic condition of affairs where some Irish cattle always kept to drained land have now become chronic cases of redwater, while the cattle of the

peasants, pastured largely on bogland, show no sign of disease.

From the foregoing remarks it is obvious that no general statement can be made regarding preventive measures, since no two places are under the same biological and climatic conditions. Hand-picking of ticks, liming of pastures, together with observance of quarantine conditions, are certainly efficacious in small outbreaks, and the use of various arsenical dips and sprays, paraffin and petrol washes and other preparations undoubtedly is of much assistance. When large areas are affected, the carrier must be ascertained and its biology most carefully studied.

The life-history of every parasite contains a vulnerable spot, and a systematic attack on the organism must be made at this period if it is to be of effect. There is little doubt that in the case of the carriers of redwater the weakest period is the larval stage, and it is for the destruction of the larvæ that the greatest efforts need to be made. It is also true that cattle and sheep will die from "tick-worry" without necessarily incurring redwater. Though this is a small occurrence in comparison with what follows redwater, yet it is sufficiently important to justify an "anti-tick" crusade.

Finally, a word of warning is needed with regard to the possibilities of the carriage of disease to hitherto immune countries. It is not sufficient that cattle exported alive from infected areas are free from disease and from ticks. Any hay, straw, and corn from such places need the strictest possible examination, for larval ticks have been found on the

stalks of grass and in imported hay, and adults have been reared from the same in England. There is not much doubt that these larvæ would have developed equally well in an English cowshed. Another source of infection often overlooked is the hoofs of animals. Small larvæ, both of ticks and of worms, have been found in the cracks of hoofs of cattle and between their toes, while scarcely discernible spaces between the hoofs and shoes of horses have been found to contain minute parasites that might be of very serious import later on. It is obvious that great care needs to be exercised both in the buying of foreign stock and of foreign hay. The cattle trade of Great Britain is of very great importance, and all support should be given to aid thoroughly scientific investigations of the cattle diseases in the various parts of the world trading with Great Britain.

In this chapter we have dealt with the parasites affecting the blood-corpuscles of the larger numbers of cattle, but it should be mentioned that other parasites allied to *Piroplasma*, and named *Nicolli*, *Nuttallia*, etc., have been described and differentiated from time to time, and have been classified on the basis of morphology and pathology by Professor França, whose work we commend to the notice of those interested in the cattle, sheep, and horse industry of Greater Britain.

CHAPTER X

KALA-AZAR AND ORIENTAL SORE

AMONG the most serious drawbacks to the colonization or profitable working of East and Central Africa, the occurrence of the tsetse flies, fatal to both men and cattle, have been considered. Egypt in the north, and the Cape in the south of Africa, while free from tsetse flies affecting man, are threatened with a danger from diseases, imported especially from India and the East, that are fatal to native and European alike. Many thousands of natives from Southern India go to South Africa each year for work, and among them, despite all the care taken by the medical immigration officers, cases of blood and skin diseases break out and also spread. The danger is not only felt with regard to Africa, but is also an impediment to progress in India. Three of these diseases may now be considered in turn. The first is known as Kala-azar, or the "black malady," and occurs more especially in India and China. Another, but far less fatal malady, is known variously as Delhi Boil, Aleppo Button, Bouton d'Orient, Tropical Sore, and Oriental Sore, as well as by other local names. The names are not signifi-

cant of the geographical distribution of the latter disease, for it is far from being confined to the East, and unfortunately has spread along the shores of the Mediterranean and has invaded the New World. The third of these nearly allied complaints afflicts children more than adults, and is consequently known as Infantile Kala-azar. This has a special interest, inasmuch as dogs, too, are infected by it and can communicate it to children associating with them. It is proposed to consider each of these diseases in some detail, but it is necessary to mention that they are due to three species of the blood-parasite known as the Leishman-Donovan body.

Indian Kala-azar is due to the parasite known as *Leishmania* (or *Herpetomonas*) *donovani*. It is parasitic not only in the blood, but in the cells lining the bloodvessels of the spleen, liver, lymphatic glands, bone-marrow, and intestinal canal. *Leishmania donovani* thus is distributed through the human system and usually has fatal effects. Oriental sore, on the other hand, is more restricted to the skin and is usually benign. Infantile Kala-azar, when once established, commonly runs a fatal course in children.

The parasites of Indian Kala-azar (Fig. 38) occur sometimes singly, more often in clusters within their host cell, which is often a leucocyte or a cell from the lining of the bloodvessels. They are most abundant in the spleen and liver. Each parasite (Fig. 38, A-D) strongly resembles the non-flagellate stage of ordinary Herpetomonads. It possesses a definite body, an oval nucleus, and usually a bar-

shaped blepharoplast. Longitudinal division occurs, just as in the insect flagellate. In fact, there is now good evidence that the so-called Leishman-Donovan body, or *Leishmania donovani*, is a developmental form or resting stage of a herpetomonad which may occur

in the bed bug of India, *Cimex rotundatus*. When attempts have been made to "grow" Kala-azar parasites artificially in test-tubes, it has been a matter of some difficulty to induce development. But citrated splenic blood containing parasites, when kept at 22° to 25° C., showed active flagellates swimming therein, and the stages in the development from a small, motionless oval

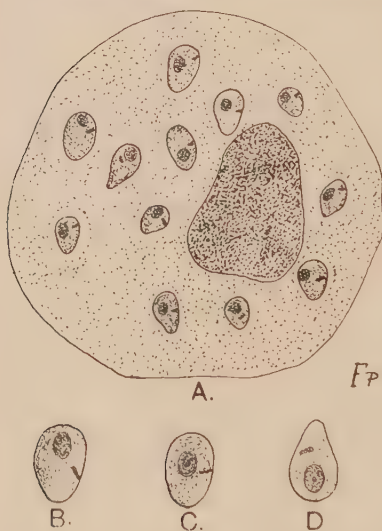


FIG. 38—THE PARASITE OF KALA-AZAR IN THE BLOOD

A, Mononuclear cell, containing twelve Leishman-Donovan bodies; B, C, D, three parasites free in the bloodstream

body to an active, elongate form with a lashing flagellum, could be followed. However, it may be a long way between what happens to an organism in a test-tube and what occurs in Nature, where conditions are more variable and less easily controlled. Conse-

quently, it was suggested that perhaps developmental stages might be found in some insect that probably spread the disease. Thenceforward, the quest of the carrier and the development of the parasite have produced an enormous amount of research on the part of various workers; but, unfortunately, the final identity of the carrier of the disease has not been established. In fact, it seems probable that more than one insect may be involved in the transference of this dread disease in different parts of the world.

The quest of the carrier involved a study both of the distribution of the disease and also of the biting insects that were most common in the infected districts. Kala-azar may be permanently located in a place, when it is said to be endemic; or it may merely be temporary, having been introduced by the advent of sick persons from an endemic area. The original home of the malady seems to have been Assam, and numerous places along the valley of the Brahmaputra are infected. When the spread of Kala-azar along the Brahmaputra valley, and especially in Assam, was investigated by Rogers, it was found that the epidemic was checked by a narrow region between the river and the Mikir Hills, and had not spread farther north. Unfortunately, it has now spread westward through Bengal, this time following the valley of the Ganges. On the south of the Ganges the Orissa country is infected, while the south-east coast also is an area where the disease is located, Madras being its chief stronghold. The valleys of the Ganges and Brahmaputra and the small but virulent centre at Madras represent roughly

the disease centres from whence it has spread to many parts of India, though fortunately it has not become permanently established in these other places. It has been found, too, that in great centres like Madras, there are some Kala-azar houses—that is, houses where person after person living in them has succumbed to the complaint. There are also cases of Kala-azar families, whose members have contracted the disease successively.

In Indian Kala-azar there appears to be no limit to the age of the person attacked. Young and old alike suffer. The distribution, then, of the infected persons presents some difficulties, but the method of transmission has presented far greater ones. Investigations showed that contact with other infected persons did not explain the transference, nor was Kala-azar an air-borne disease. The persons afflicted were rarely aware of the time when they contracted the complaint, nor of any circumstances attending it. The disease “appeared suddenly.” Having excluded air, water, food, and contact, some blood-sucking insect was apparently incriminated. India contains numerous animals that are skin parasites. Various bed-bugs, fleas, head and body lice, sucking and stabbing flies and ticks are found. Which of these was the culprit, and was there more than one carrier? Such were the problems facing the investigators.

From a consideration of the disease, its onset and its distribution, it was obvious that if one carrier alone occurred, it must be common and also widely distributed. In the second place, the parasite is not particularly common in the peripheral blood, so

that the insect transmitting it must be a relatively hearty feeder ; the insect must also be a fairly "long-tongued" one in order to reach the parasite. Another factor needing consideration was the way in which Kala-azar repeatedly occurred in some houses, while neighbouring ones remained free of it. This suggested that the insect carrier was one which would return to its old haunts and would remain there until new victims were available for food. Captain Patton, working in Madras, had considered all these problems, and by a process of exclusion concluded that the bed-bugs, extremely common in Madras, were the most likely insects to be concerned. Their wide distribution, voracious feeding, retreating into hiding, and possession of moderately long sucking apparatus were all in their favour. The natives also aided in their ubiquity by their reluctance to destroy vermin, which, being merely deposited in the street after capture, promptly returned into the house whence they had been ejected, or entered one in the immediate neighbourhood.

Prolonged search was made by Patton of all the blood-sucking insects found in infected areas. They included head lice, body lice, and ticks that frequented the person or the dwelling, the gnat *Culex fatigans*, the mosquitoes *Neocellia stephensi* and *Stegomyia ingens*, and the tick *Ornithodoros savignyi*, which were common pests indoors and outdoors alike. Some of the insects were found to contain natural flagellates, even when they were bred in the laboratory. When they were fed on patients, in no case did the Leishman-Donovan bodies undergo any development, nor were these

insects able to transmit the disease when allowed to bite healthy animals. The parasites merely degenerated in the insects employed.

Attention was given at the same time to the bed-bugs which were so extremely common. By a series of careful experiments, Captain Patton proved that

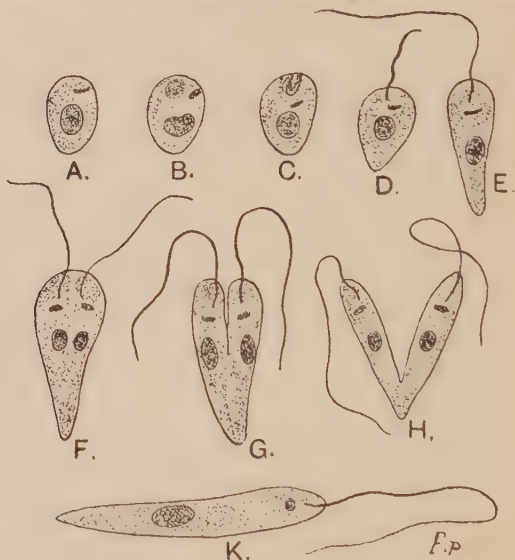


FIG. 39—THE PARASITE OF KALA-AZAR IN THE BUG

A-D, Show the gradual development of the flagellum ; E, very young flagellate ; F-H, division stages ; K, full-grown flagellate

the Kala-azar parasites actually underwent development in the Indian bed-bug, *Cimex rotundatus*. Once the parasites had been absorbed by the bug, the leucocytes and cells containing them (Fig. 38, A) began to degenerate, and the small parasites were set free (Fig. 39, A). Some began to elongate almost at

once and to grow flagella (Fig. 39, *B-E*), just as the pre-flagellate form of a *Herpetomonas* does. The development went on best in the mid-gut of the bug, and the flagellates (Fig. 39, *K*) formed there were active and healthy. Multiplication by repeated longitudinal division also proceeded (Fig. 39, *F-H*). Some forms also divided before the flagella were produced, but these developed flagella exactly as did those that produced them previous to division. Finally, in the far mid-gut and hind-gut the parasites gradually reassumed the more resistant post-flagellate forms.

The post-flagellates seemed to be the form most suited for direct transmission to man. When bugs begin to suck blood, a small quantity of their gut contents is regurgitated. There is no mechanism in the insects' gut to prevent this. With the fluid thus expelled are probably some of the post-flagellate parasites, and these, entering the wound, may be seized upon by the leucocytes which, however, are incapable of destroying them. There they may grow and multiply, and finally, having destroyed their host cells, they may be set free into the blood-stream. Such is a possible sequence of events, should Kala-azar be transmitted by the bed-bug.

Now, the organisms do not possess flagella while in the human system, and consequently cannot swim about in the blood-current as trypanosomes do. As a result, they are found in greatest numbers in those organs that may be described as backwaters of the blood-stream—namely, the spleen, which becomes enormously enlarged, the lymphatic glands, the bone-marrow, and the liver. The number present in the

circulating blood varies considerably, more being present at one stage of the disease than at another, but compared with the numbers in the spleen, they are relatively rare. The disease is a most serious one, for 80 per cent. of those infected with it in India die from its effects. It is most insidious, and often a patient is unaware that it is present. It develops slowly, and often takes months before it is fatal. Often it has been diagnosed first as typhoid or malaria, and death may be caused by exhaustion, dysentery, pneumonia, or peritonitis intervening. Enlargement of the spleen and liver is characteristic of the complaint, and acute attacks of dysentery may occur at one stage. Emaciation also is common.

Various treatments have been tried, but with little success. Quinine, so useful in malaria, is not so here when taken by the mouth, but when injected beneath the skin it is said to be beneficial. The high death-rate in India is remarkable, and its importance not to be underestimated. It is probable that it might be even greater than hospital statistics give, for sufferers know now that very little as a rule can be done for them, and hence are averse from entering hospitals. With such a deadly disease devastating parts of our Indian Empire, and spreading also because of the movements of the natives from place to place, the importance of all accurate work on the subject cannot be exaggerated. Kala-azar is already known in Egypt and the Sudan, and fatal cases have occurred among both Europeans and natives there. It is possible that it may be endemic in Egypt and be always present, but on the other hand,

it is possible that it has been imported from the East. Both commerce and emigration are affected adversely by the occurrence of this fatal disease in Southern India.

Recently much attention has been given to a malady more especially prevalent among children occurring on the Mediterranean littoral, both African and European. It is often called Infantile Kala-azar, as it resembles Kala-azar and is chiefly prevalent among children. A complaint known as infantile splenic anæmia has long been recognized in Italy, and is the same as Infantile Kala-azar. On the European side, Crete, Greece, Turkey, Italy, Malta, Sicily, and Portugal, all have the disease, while it has been reported from Algeria, Tunis, and Tripoli, on the African coast. Sicily and Calabria are very heavily infected.

The symptoms of infantile Kala-azar resemble those of the Indian form, and the parasites (often called *Leishmania infantum*) collect largely in the spleen, which becomes much enlarged, and in the lymphatics, liver, lungs, and pancreas. There is much anæmia and weakness prior to death. In one case Dr. Critien found the parasites in the stools of a three-years-old Maltese child, but this is the only case wherein it has been reported.

L. infantum strongly resembles the Indian Kala-azar parasite in appearance. While it is most deadly to the young, some cases are known when heavily-infected children have recovered suddenly and without treatment. Such cases of spontaneous recovery are of great importance, for it will probably be by

study of the blood of such patients that the cure for the disease will be found.

Though *L. infantum* chiefly affects children, it is not confined to them, for it has been recorded from people aged 17 at Tripoli, 18 at Stromboli, 19 at Rome, and a case at the age of 38 was noted in Calabria. These are somewhat exceptional, but they serve to link the range of the Mediterranean with the Indian form, though, unlike the Indian parasite, it is easy to produce multiplication of *L. infantum* on artificial substances, or cultures, and it can readily be reproduced in dogs and monkeys. It is almost impossible to reproduce the Indian disease in animals, and very few cases of success have been recorded.

During the investigations of this infantile Kala-azar, two startling discoveries were made. In the first case a large number of dogs was found harbouring a parasite identical with *L. infantum* in their blood; also they were short-lived when the parasite was present. In the second case it was found that children living in contact with infected dogs also had Kala-azar. This at once suggested that if the parasite of dog and child were identical, some insect that frequents both man and dog was responsible for the transference of the disease to the human host. Much work was done and by various means. An investigation of the dog parasite was made, and in order to study the disease as far as possible without other complications intervening, specially bred dogs free from the disease were artificially infected. The malady took one of two courses. In young animals

it rapidly became acute and was fatal to the dogs in three to five months. When older dogs were used, the disease ran a chronic course, and the animals lived up to seventeen or eighteen months. The latter course was in marked contrast to the acute form, as the animals appeared to be well, apart from loss of weight, and behaved normally. The acute cases were accompanied by an irregular fever, progressive wasting occurred, and diarrhœa was often present. Disturbances of the nervous system often caused a partial paralysis of the hind-quarters, coma set in, and death followed. The parasites, as in the Indian Kala-azar, were mainly in the internal organs and were rare in the peripheral blood except at times of fever. The offspring of infected bitches were not infected; at least, hereditary infection was not demonstrated.

In Tunis, a few dogs—9 out of 519 animals—were found to be spontaneously infected, and in Algiers, though the rate was 9 out of 125, it could not be considered great. But in Europe, different observers found an enormous increase in the numbers of naturally infected dogs. For instance, Basile, working at Bordonaro, found that 27 dogs out of 33 examined contained the parasites, while at Rome 16 out of 60 were in the same condition. Other observers have found similar results in Portugal, Athens, and Malta.

Basile then conducted a number of experiments with dogs and fleas, whereby he considered that he had shown that the dog flea, *Ctenocephalus canis*, was the carrier of the disease from dog to dog, from dog

to man, and from man to man, the human flea, *Pulex irritans*, being suspected of having a share in the latter work also. Basile succeeded in infecting young clean dogs by putting them in kennels with infected ones, and considered that the fleas passed from the infected to the healthy animals. The proof that the dog flea is the natural infective agent was not really afforded by Basile's work, for instead of feeding fleas on a heavily infected dog, he fed them on infected spleen pulp, to which, of course, they could not have access in Nature. With regard to the connexion of the dog flea and man, dog fleas were obtained from beds, mattresses, and pillows of infected persons, and as a result of examining 1,000 fleas thus obtained from Bordonaro, four were found to contain flagellates. Here, again, an element of doubt was introduced, for the characteristic form of the leucocyte containing the unchanged parasite is not mentioned, and the cycle of changes undergone by the parasite in the flea was not fully detailed. The fact that Herpetomonads, which are true parasites of the dog flea itself, and have no connexion with the dog, are known, renders the paucity of infection of these fleas with flagellates somewhat suspicious. It suggests a natural flagellate of the flea, rather than a developmental stage of the parasite of the dog or of man.

The coincidence of infantile and canine Kala-azar may have some important connexion, or it may be accidental. While it seems likely that the flea does convey the malady from dog to dog, the case for transference from dog to man is less complete, and

more work is needed before a decisive opinion can be given on this matter.

Other workers have given attention to flies and mosquitoes as the possible channels of infection, and Franchini has done some work in this direction. He used *Anopheles*; but whereas he could induce the development of the parasite within the mosquito's gut, yet the results were not conclusive, as the insects were fed on cultures of Kala-azar and not on animals. What he has shown is that the parasite can live in the gut of an *Anopheles*, which therefore is a possible transmitter of infantile and canine Kala-azar. The quest for the carrier, then, must still be pursued, as with Indian Kala-azar. The recognition of the occurrence of natural flagellates of the blood-sucking insects, and their exclusion from the experiments, is a matter of vital importance. The study of natural flagellates in both blood-sucking and plant-feeding insects thus assumes an importance that is infinitely greater to-day than it was when the pioneer worker on insect flagellates, Captain Patton, set forth the idea some years ago.

India is not afflicted with Kala-azar only. That fearful disease is largely localized, though its distribution is increasing. But another disease, marked by disfiguring sores on the skin, is known there under the names of Oriental Sore, Cambay Boil, Delhi Boil, and other local names. It is known elsewhere, for instance, as "Clou de Gafsa" in Tunis, and as "Aleppo Button" and "Bagdad Sore." The organism incriminated is *Leishmania tropica*. This disease produces peculiarly disfiguring scars,

and the wounds or lesions are found not only on most parts of the body, but even on the face and scalp. The parasites strongly resemble those of Kala-azar, and can be cultivated fairly easily on artificial media. The small oval forms then gradually develop a flagellum, and are capable of active movements. They divide rapidly into two, and the division of each daughter form may recommence before the two original ones are completely separated, so that rosettes of parasites are produced.

When a drop of fluid from a sore is introduced under the skin, the spot pricked soon heals up. After an interval varying from about sixteen days to six months, a small nodule makes its appearance, and later the skin may become broken or covered with scabs and scales, which, except for a few perforations, remain intact almost to the termination of the disease. A thin whitish fluid oozes gradually from the sore, and in cases where the latter does not become contaminated with other organisms such as bacteria, the margins swell from time to time, usually one side being more noticeable than the other. If a drop of liquid be taken from the swollen edge, it is found to contain the parasites, and usually if the blood be examined some distance from the infected spots, parasites can be found in it at these swollen periods. This feature recalls what is found in Kala-azar, for in that disease there is a periodic extension of the parasitic area, the intestine being particularly affected, and dysenteric discharges occurring as a result. Naturally, times at which the edges of the sore are swollen are those when detection of the

parasite and diagnosis of the disease therefrom are most easily made. Should the sores completely break, the parasite rapidly disappears from them, and the outlines of the parasitic area vanish. In most cases no secondary lesions appear near the first sore, but the virus may be carried to other exposed spots by the finger-nails—*e.g.*, children scratch a sore, and then by scratching some other healthy spot, inoculate themselves there, though the new sore does not appear, perhaps, for a couple of months. True Oriental sore does not run a fatal course as does Kala-azar, and it is also amenable to treatment with drugs, among which potassium permanganate has been quite successful. At Bushire Hospital, the patient's skin around the sore was protected by a thick layer of vaseline, and the surface of the ulcer powdered with potassium permanganate, which was kept in position by a pad of gauze and a bandage. The treatment causes great pain for six to eight hours, but, at the most, three treatments are necessary before the sore becomes a simple ulcer, well on the way to healing.

Nitrate of silver used in the form of a pencil is useful for healing sores that may appear on or near the eyes and mouth. Carbolic acid, either pure or in alcoholic solution, is used for the same purpose. Where the sore is so situated that the simple operation of excision can be carried out, the healing is usually rapid and is not followed by a relapse.

But prevention is better than cure, and hence much time has been given, by many observers, to attempts to find out how the disease is spread.

Unfortunately, many workers have relied on what has been observed in cultures of the parasite in test-tubes, amid somewhat unnatural surroundings, and hence their results are less valuable, for conditions in test-tubes on artificial media are not necessarily criteria of what occurs naturally, as in the alimentary canal of some biting insect or tick. From the distribution of cases and the nature of the malady there is little or no doubt that some insect or tick, or perhaps more than one, is responsible for the spread of the disease from man to man. The distribution of Oriental Sore is a very wide one. It is known in Europe, Asia, Africa, and America, and is more prevalent in some districts than in others. Consequently, there is a possibility of more than one ecto-parasite being involved. Dealing first with the problem of the transmitter in Asia, we find that a considerable amount of work has been done, without, unfortunately, absolutely positive results, though certain insects are definitely suspected, as *Leishmania tropica* can develop within them. One of the great centres for Oriental Sore in India is Cambay. While the town is heavily infected, the districts outside are relatively or entirely free. Investigations have been undertaken there by Captain Patton, of the Indian Medical Service, and by an Indian, Dr. Row. The latter investigator worked largely with cultures on which he fed house-flies, but found that the parasite soon disappeared from the food-canal of the fly, which he considers to be a possible transmitter of the disease. Captain Patton, working by the method of exclusion, used numerous insects

in direct experiments, feeding them on sores, and then dissecting some so fed, while others were allowed to feed again on healthy animals or on himself. First, by careful experiment on himself, he proved that the fly could not infect direct by carrying infected material on its legs or its proboscis, nor did a long series of observations on cuts, scratches, sores, or ulcers of children throughout the fly season show a single parasite. Again, at any rate in Cambay, the parasite did not develop in the two most common house-flies, nor could it be found that the disease spread in a house during the fly season, even when several people with suitable sores were dwelling therein. Moreover, the sore is most frequently contracted in Cambay during the very severe, cold weather, when house-flies are extremely scarce.

Both body and head lice, several mosquitoes, and human and dog fleas, gave negative results. The most common insect in the houses of the people of Cambay was the bed-bug, *Cimex rotundatus*. By a number of experiments Captain Patton found that the parasites readily develop in the stomach of a bug so long as the temperature does not go above 25° C., and it is worth noting that Oriental Sore only occurs in those parts of India where there is decidedly cold weather. Next, the investigator showed that young, immature bugs were best for the development of the parasite, and that in them it developed rapidly.

Investigations were made of the insects likely to return if disturbed when feeding, and the mosquito *Stegomyia* and the bed-bug were found to behave

in this way. Of these two, in Cambay, at any rate, all the evidence is in favour of the bed-bug. In other places, where bed-bugs are uncommon, some other carrier must be sought. This is well recognized by Captain Patton, who says his results "apply to Oriental Sore in Cambay," and that he well realizes that the parasite "may have more than one invertebrate host"—a scientific statement, and one that should command him more generous treatment than has been accorded him by workers in other places under different conditions.

Dr. Wenyon, working at Bagdad, used house-flies and *Stomoxys*, the stable fly, but found that while they would feed on the sore, no development of the parasite occurred within them. *Culex fatigans* and *Stegomyia fasciata* also were used, and in the latter the parasite underwent some development. When attempts were made to reproduce the disease by means of it, they failed. Wenyon found that the parasite would develop in the bed-bug, but considered that the insects were too rare to account for the numbers of cases of Oriental Sore in Bagdad. He concluded that the house-fly might often act as a mechanical carrier, but more usually either one of the mosquitoes, or the sand-fly, *Phlebotomus*, but no experiments were made with the last insect. The problem of the carrier of Oriental Sore in Bagdad, then, still remains unsolved. Later experiments, conducted in Aleppo, failed to incriminate *Phlebotomus* as a transmitter.

Skin diseases due to *Leishmania* also occur in Egypt, the Sudan, and North Africa. Here the

sores do not seem to ulcerate so markedly as they do in Asia, though they may be numerous and on all parts of the body. It is unknown how the disease is spread. The natives consider that the bed-bug and the sand-fly are probably responsible, while accidental acquisition by contact was possible in the case of certain soldiers who slept with infected comrades, though here there was also the possibility of insect agency.

South America also is now a home of skin leishmaniasis. The disease is known in Dutch Guiana as "Boschyaws," in British Guiana as "Forest yaws," while in French Guiana it is called "Pian-bois." Dr. Flu, who has worked in Dutch Guiana, brings some evidence to show that ticks carry the disease. The malady also occurs in Brazil and Panama. In South America it seems to affect the mucous membrane of the mouth, lips, and nose, as well as the ears and skin. The disease lasts a variable time, and produces emaciation and sometimes grave prostration.

The appearance and structure of the ulcers seem to differ considerably in Oriental Sore as observed in the Eastern and in the Western Worlds. Careful consideration of these appearances, the duration of the disease, possible carrier and pathological effects, has led to the opinion that several varieties of skin leishmaniasis occur, and that the diseases of the skin known under that name, or that of Oriental Sore, will need to be re-classified. Until the full life-history of the parasite has been worked out in each case, attempts at natural classification can only fail,

though from the point of view of medical treatment, they may be of use for the time being. Until the quest of the carrier has been accomplished, little value can accrue from classifications based on incomplete knowledge. Similarly, it is not yet possible to pronounce with certainty as to whether *Leishmania donovani* of Indian Kala-azar is identical with *L. infantum* of the Mediterranean region, as some authors consider. Leishmaniasis is constantly being recorded from places hitherto believed to be free from the disease, so that the geographical distribution is being extended, as in China.

Further investigations on immunity against leishmaniasis will be awaited with interest, as it is already known that one attack of *Leishmania tropica* confers immunity for life against Oriental Sore, and there is some evidence that inoculation with the milder leishmaniasis may confer immunity against more virulent forms.

CHAPTER XI

MICROSPORIDIOSIS—BEE AND SILKWORM DISEASES

AMONG the romances of Science, few are of greater interest and economic importance than those centring round the name of Pasteur, and one of his researches was the means of saving an entire industry—that of the preparation of raw silk—to France. Pasteur it was, who identified small oval bodies found in the corpses of silkworms as the cause of their death. He also showed that the moths, when infected, could transmit the same disease to the eggs, and that the young were born infected. The fatal disease—*pébrine*—which devastated the silkworm-rearing establishments of France, was first identified by Pasteur with the animal parasite now known as *Nosema bombycis*. It was due to his ingenuity that preventive measures were devised; for, by microscopical examination of the parents, and by comparing the weight of diseased and healthy eggs, it became possible to destroy the infected ones and to preserve only healthy stock. Pasteur's work was, however, incomplete, for the life-history of the parasite and the method of its

development within the silkworm were not worked out, the interest at the time centring around the economic side of the work rather than the purely scientific.

Since the time of Pasteur, many organisms allied to the *Nosema* of pébrine have been discovered, and some fish tumours and wasting diseases of other insects have been found to be due to members of the same group, the Microsporidia, or to the nearly related group, the Myxosporidia. An interesting point in connexion with the distribution of the two groups is that the Microsporidia seem to have advanced farther along the road of parasitism than the Myxosporidia. Certain of the Microsporidia, such as the *Nosema bombycis* of the silkworm, have developed both enormous powers of multiplication within one host and a capacity for invading and dwelling within each and every tissue and organ of the animal that shelters them. *N. bombycis* occurs in the alimentary tract, fat-body, muscles, circulatory system and reproductive organs of its host, and is easily able to multiply in all of them, thereby showing great powers of adaptation to the very different media by which it is surrounded. Many of the Myxosporidia, on the other hand, have a more restricted distribution, and in many cases are found parasitic in the gall-bladders or kidney tubules of their hosts, or more rarely in skin tumours.

Thanks to the preventive measures adopted in France, pébrine among silkworms has practically disappeared, and to the present generation of French scientists and silkworm rearers, pébrine belongs to

past history, and as such has an interesting historic background, but little else. In England, where the production of raw silk is not undertaken, and also in Australia, more interest is at present manifested in a parasite nearly allied to *Nosema bombycis*, which, as it destroys the bees, is named *N. apis*. Here again, the spores of the parasite were recognized before the life-cycle was investigated, and it was not till 1911 that it fell to the lot of the present writers to publish at length the life-history of the parasite, though in 1906 we had found the organism and proved it the cause of disease.

The year 1904 was noteworthy to many bee-keepers in England, for in that year, a "new" and "mysterious" disease appeared among the hives in the Isle of Wight, and was promptly termed "Isle of Wight" disease. Great precautions were taken to prevent the spread of the disease to the mainland, but unfortunately the efforts were ineffectual, and gradually outbreaks occurred from Hampshire in the south to Wick and Stornoway as the extreme limits in Scotland. Many suggestions as to the cause of the disease were made, but one after the other broke down. In 1911, on a recurrence in virulence of the outbreak, Fantham and Porter exhibited before the Zoological Society of London the parasite *N. apis*, together with specimens of infected bees, and drawings of the organisms. They announced that since 1906 they had experimentally proved that when this organism was present in the food-canals of the bees, they died rapidly, and that "Isle of Wight" victims also always contained the parasite. Bees artificially

infected with *N. apis* from victims of "Isle of Wight" disease, died in a short time. Subsequent investigations proved absolutely the correctness of their view, both with regard to the life-history of the organism and its relation to the disease. The life-history of the parasite and its action on the bees may now be given in some detail.

In many animal diseases there are distinct external signs whereby the malady can be detected and diagnosed. With the "Isle of Wight" disease, better designated microsporidiosis, there is much greater difficulty, for the bees present no external symptom that can be described as universal. The only feature at all constant is that, when the outbreak is at all severe, enormous numbers of bees die within a very short time, and often the deaths appear to be simultaneous. But in many cases certain features can be recognized. When the bees are infected with the *N. apis*, they are feeble and become incapable of flight. Often their wings are dislocated, and the unhappy victims creep about on the ground, often with their abdomens trailing, and vainly endeavour to launch themselves into the air by creeping up some taller blades of grass or projecting leaves. Others manage to reach the alighting board before the hives, but are too enfeebled to crawl into the interior, so remain outside, finally lose their balance and fall on to the ground, there to perish miserably of cold and hunger.

Other infected bees manage to fly out of the hive, and make some attempt to collect pollen or nectar. But in their weakened condition the task proves too

much, and the workers that left the hive fail to return. It is a difficult matter to detect the corpses of such bees, unless there happens to be a number in one neighbourhood, or the favourite collecting-ground or drinking-place of some special hive is known.

Nor does the death of workers from disease alone account for the enormous mortality among the hives. The healthy workers left attempt to fulfil the duties of the whole community, and inevitably succumb to overwork, while the brood, chilled by the lack of warmth from the bodies of the nursing-bees, die in their cells, and thus the colony is not replenished by the issue of the young bees.

Some infected bees show very little disposition to sting, as well as to fly. This remark applies more especially to the British black bees. No such disposition to gentleness was found among the diseased stocks of the brighter Italian bees investigated.

Another feature of some interest, because it is so marked if present at all, is the way in which infected bees soil their hives. Ordinarily, defæcation by bees takes place when the insects are on the wing, and the hive is kept scrupulously clean. But when the bees are infected with *Nosema*, it not infrequently happens that the abdomen of an infected insect is distended. The slightest touch or pressure is then sufficient to cause ejection of the abdominal contents, with the result that honey, pollen, wax, hive, and fellow-workers become spattered with excrement, rich in the resistant spores of the parasite, which are the means of the spread of the disease.

Microscopical examination of the fæces shows that the usual masses of partly digested pollen are present, and in the case of a diseased bee, the degree of digestion is far less complete than in a healthy one. In addition to these pollen masses, in some bees there are large numbers of tiny, oval, shining bodies—the spores of the parasite. These spores, if taken up by another bee chiefly in its food or drink, liberate organisms that multiply in the walls of the alimentary canal and gradually destroy them. The inability to produce sufficient digestive juice, and the irritation that the very presence of food in the stomach or intestine produces, leads to the fæcal discharge in many cases, and the symptom has been denoted “dry dysentery.” This name was given partly because the fluidity of the fæces of bees is less than that of some animals, and partly on account of the rapidity with which the discharge dries and becomes solid.

Sometimes, too, an infected colony will proceed to the exhausting and laborious task of wax-making. In some cases the infected bees are quite unable to produce normal wax, and the comb is very rough, mingled with fæces and undigested pollen; while on other occasions it darkens considerably, and so appears to be very much older than it really is. As a result of the inability to maintain the usual spotless cleanliness of the hive, there is grave danger of honey, pollen and comb all being contaminated with the disease, and hence access of robber bees should be prevented. Where robbing occurs, the disease spreads with great rapidity, and as weakly

colonies always get attacked by robbers, the area of infection is greatly extended.

The life-history of *Nosema apis* may be conveniently started at the time when the spores are absorbed by the bee either with its food or drink, or when taken up in some other way that will be discussed later. Infection takes place by way of the mouth. The spores pass into the œsophagus, and then into the honey stomach, or crop, where they remain unchanged as a rule. When they enter the chyle- or digesting stomach, the hard coat of each spore is softened by the digestive juices, and a tiny amœboid germ creeps out into the cavity of the gut. This amœbula gives rise, by division, to daughter forms, each possessing one nucleus and capable of wandering about over the epithelium of the gut (Fig. 40, A). Such forms are called planonts, or wanderers. The planonts creep about over the epithelium (Fig. 40, B) for a short time, and may increase in numbers by dividing into two, thus giving rise to small colonies or nests of planonts. Gradually the planonts penetrate between the cells, and finally enter them, thus becoming intracellular (Fig. 40, C). The planonts, once they have entered their host cells, become passive and gradually rounded or oval, and are about 0.75 to 2.5 μ in diameter. The largest, then, are about $\frac{1}{16}$ of an inch across. The parasites proceed to grow and feed, becoming trophozoites. The latter, after reaching a certain size, are capable of division to produce new forms like themselves, and thus from one original spore a large number of descendants can arise. Not only is this the case,

but more than one planont can invade any cell of the gut (Fig. 40, C). Thus, rapid increase in the numbers of the parasite within the same host is



FIG. 40—NOSEMA APIS: PLANONTS AND MERONTS

- A, Group of planonts from chyle stomach of the bee; B, amœboid planont creeping over epithelial cell of bee's gut; C, cell from the gut of the bee containing young trophozoites; D, growing uninucleate trophozoite or meront within an epithelial cell; E, meront with nucleus divided into four, about to form four spores

ensured, not only by the multiplication of single planonts within individual cells of the gut, but by the multiplication of colonies of parasites within the same cell.

Sometimes a planont does not enter an epithelial cell of the gut after having penetrated between the cells, but continues onwards and reaches the body cavity or hæmocœl of the bee. There it may remain, or after a short time it may return into the gut. Other planonts, as previously mentioned, penetrate the gut epithelium direct.

In either case the motile planont becomes quiescent and develops as a trophozoite (Fig. 40, *D*). After growth has proceeded for a time, the nucleus of the trophozoite divides into two. The body protoplasm divides also, and two daughter forms are produced. These dividing forms are known as meronts or schizonts. There are several variations in the ways by which daughter meronts are produced, but three main types are encountered. The simplest form is that in which the parasite divides into two practically identical parts. The nucleus lengthens and its substance concentrates in the ends, so that it has the appearance of a dumb-bell. The thin strand that connects the two heads gradually separates, and the body substance divides at the same time, so that two new meronts are formed. Meronts may be rounded, oval, or elongate.

Sometimes a chain of meronts is produced by the incomplete separation of the original two. If the number of succeeding divisions is the same in both of the daughter forms, a chain of an even number of individuals is produced; but when irregularity occurs, chains of three, five, or more, are produced. This second method of meront formation has not been met with so commonly in *Nosema apis* in bees in

England, though it occurs. It is more common in *N. bombycis* in the silkworm.

The third case is that in which a meront grows very large before any division of its nucleus begins. When such a large meront is actually within one of the epithelial cells of the host, it usually happens that the nucleus of the meront divides into four (Fig. 40, *E*), and the greater part of the body cytoplasm divides into four also. Four daughter meronts, then, are produced within the remains of their parent form. Occasionally, the large meronts show great delay in the separation of their cytoplasm, though the nuclei multiply with rapidity. Ultimately each of these nuclei collects cytoplasm around itself and becomes a spore. These large meronts may lie within cells of the gut epithelium, but more often they are found between the cells.

The formation of the digestive juices of the bee is peculiar, for the cells containing the digestive fluids are themselves cast off into the gut cavity, and it is not until they disintegrate there that their secretion is liberated. Should the cells contain parasites (Fig. 41, *B*), these are set free at the same time as the digestive fluids, and, consequently, both planonts, large and small meronts, and spores of the *Nosema* can be found freely floating in the gut contents. Should the cells not be shed, the nests of meronts continue their development, until each infected cell contains a colony of meronts, each of which ultimately becomes a shining, oval spore, the colony lying within the space occupied at first by the original meront (Fig. 41, *A*).

It has been mentioned that several planonts may invade the same cell, but they do not usually invade it simultaneously. The result is that mature spores, meronts engaged in active division, and planonts may all be present at the same time in one cell, so that crops of spores can be liberated successively into the gut. It is worthy of note that in many cases the injury to the intestinal wall, due to the younger stages (meronts) of the parasite, are so great that the bee dies as a result of their action. In that case, the career of the parasite also comes prematurely to an end, for hitherto all attempts at infecting bees with the young stages of the parasites have been failures. So far as our knowledge goes at present, it is the spores, and the spores only, of the parasite that are infective. The death of the bee in which young, multiplicative stages of the parasite occur, then, also terminates the existence of the parasites. But in most cases a few at least of the meront stages of *Nosema apis* are carried farther, and the parasites proceed to the formation of spores, destined by their great powers of resistance to perpetuate the race in yet another host.

Now, according to the position of the meronts, as single individuals or as numbers within a parent meront, there is developed a single free spore or a colony of several spores within the parent. The meront which is about to become a spore is known as a sporont or pansporoblast. It concentrates its cytoplasm around its nucleus and gradually alters its character and becomes the sporoblast. This ceases to grow, secretes a spore coat or sporo-

cyst around itself, and becomes a spore (Fig. 41, A-E). Little by little the spore-coat thickens until

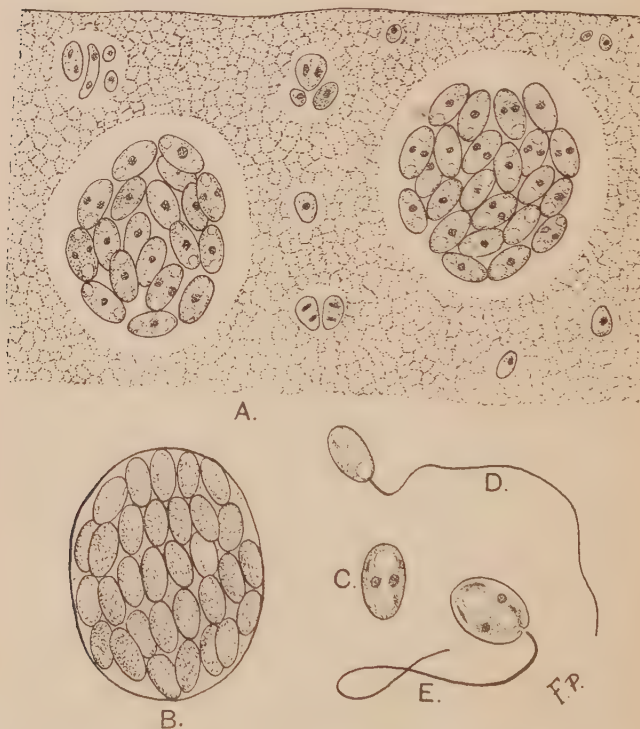


FIG. 41—*NOSEMA APIS*: SPORES AND SPORE STRUCTURE

- A, Piece of epithelium from the chyle stomach of the bee, showing two colonies of sporoblasts and young spores of *N. apis*. The tissue near the colonies shows eight sets of meronts, some of which have recently entered the tissue. B, Epithelial cell crowded with spores; fresh preparation. C, Spore showing all five nuclei. D, Fresh spore showing discharged polar filament. E, Spore from which amœbula is about to issue. Polar filament has been expelled, but is lying near. Sporoplasmic nuclei show well, sporocyst nuclei distinct, nucleus of polar capsule degenerating. C and E are on a larger scale than A, B, D

the progress of events going on within is quite obscured. When the sporoblast has only just begun to form the coat, the protoplasm gradually concentrates at one end of the spore, and as a result a vacuole, or space, containing liquid appears at one end. This end is known as the posterior or hinder end of the spore, and the vacuole is called the posterior vacuole. Later, a second vacuole, with much firmer limits or boundaries to it, appears at the anterior end of the spore, and this second one is known as the polar capsule (Fig. 41, *A, D*). From the now girdle-like contents of the spore—henceforth known as the sporoplasm (Fig. 41, *C, D, E*)—a long strand of protoplasm with an elastic core is formed, and this coils up within the posterior vacuole and polar capsule, and is known as the polar filament. Under certain circumstances this thread can be ejected through the polar capsule with considerable force, and so anchor the spore to the epithelium of the alimentary tract.

Not only are there these changes in the sporoplasm, but great changes go on in the nucleus as well. The original nucleus has many potentialities, which now manifest themselves. The nucleus first divides into two, each daughter nucleus with a different destiny (Fig. 41, *A*). One of the two nuclei separates from the other, and again divides into two. Each of these nuclei becomes lengthened and threadlike (Fig. 41, *C, E*) and moves away to the edge of the spore. They control the growth of the sporocyst, which now grows far more rapidly than before. At the same time, the second of the

original nuclei gives off a small bud-like nucleus, which migrates to the polar capsule and there controls its growth. This is known as the polar capsule or capsulogenous nucleus. The remainder of the second nucleus again divides into two, so that the spore contains five nuclei. These last two nuclei remain in the sporoplasm.

It should be noted that these nuclei are not all of the same size and shape, nor do they all persist for the same length of time. When the sporocyst nuclei have completed their work, they often gradually degenerate and disappear. The same occurs with the polar capsule nucleus, and consequently spores with less than five nuclei are found.

While these nuclear divisions are occurring, the sporocyst is becoming very thick and opaque, and it is often necessary to use strong reagents such as creosote to render them less opaque in order to see the contents after staining. The five nuclei in the spore are of much interest, for they represent an attempt at division of labour in the structure of a Protozoön. Until the sporocyst nuclei are formed, the sporocyst develops but very little. It increases rapidly after their formation. Similarly the development of the polar filament proceeds apace only under the controlling influence of the associated nucleus. The two sporoplasmic nuclei control the activity of the sporoplasm, which ultimately leaves the spore and becomes the young amœbula with which the life-history began.

When the spores of *Nosema* rupture the cells in which they are lodged, or the latter are set free into

the cavity of the gut and burst there, they remain inactive unless taken up by another bee, or, perhaps, a wasp. Once again swallowed with food, the spores rarely undergo change till they reach the chyle stomach of the host. Then, under the influence of the digestive juices, the sporocyst of each spore softens. At the same time, the movements of the digestive tube render some sort of anchorage necessary. The polar filament is shot out vigorously, and, penetrating between the cells of the epithelium, fixes the spore for the time. The sporoplasm now moves forwards, and as it presses around the polar capsule, and begins to leave the spore through the aperture made by the polar filament, the latter structure is often snapped off, or forced completely out of the cell (Fig. 41, *E*) in front of the issuing amœbula. Empty "shells" are then to be found, mingled with food débris, and can be easily recognized as empty if they are compared with the glistening, opaque spores, whose brilliancy is far greater than that of the empty spore.

The size of the oval spore may be gathered from the fact that it is about $\frac{1}{3000}$ of an inch long, and that its breadth is about half its length—that is, in terms of measurement used in microscopy, the dimensions of a *Nosema* spore average $5\ \mu$ by $2.5\ \mu$.

The life-history of *Nosema apis* is largely confined to the alimentary tract, but *N. bombycis* of the silk-worm, which has a life-cycle similar to that of the bee parasite, is more deadly than the latter, for it has acquired the power of invading every part of the body and of developing fully therein. *N. apis* is

however, on the way to becoming as plastic as *N. bombycis*, for the planonts have acquired the power of passing through the walls of the alimentary canal and reaching the space that surrounds the viscera, which is the body cavity or hæmocœl. The latter name is given because the cavity contains a thin and practically colourless fluid, which is the blood of the bee. When the planonts reach the hæmocœl they can divide and form meronts there, and the latter can become spores. But though the parasites are carried by the blood into many organs of the body, they do not seem to have much power of developing in these organs, and so are unlike *N. bombycis*, which develops equally well in any organ of the body.

The distribution of *N. apis* is thus of interest. The œsophagus (Fig. 42, *æ.*) and honey stomach, or crop (Fig. 42, *c.*), rarely contain more than the freshly absorbed spores of the parasite, though occasionally amœboid planonts have been seen creeping over the lining of the crop. Beyond the crop is a small lock or stopper (Fig. 42, *s.*) that communicates with the more muscular chyle stomach (Fig. 42, *c.s.*). The walls of this organ are more easily attacked, and the parasites readily penetrate its cells. But the distribution of the parasites is very varied—one part of the organ may be swarming with parasites, while an adjacent area is practically uninfected. The same conditions occur in the small intestine (Fig. 42, *s.i.*), but self-infection occurs here, for some of the spores formed in the chyle stomach liberate their amœbulæ in the intestine. The

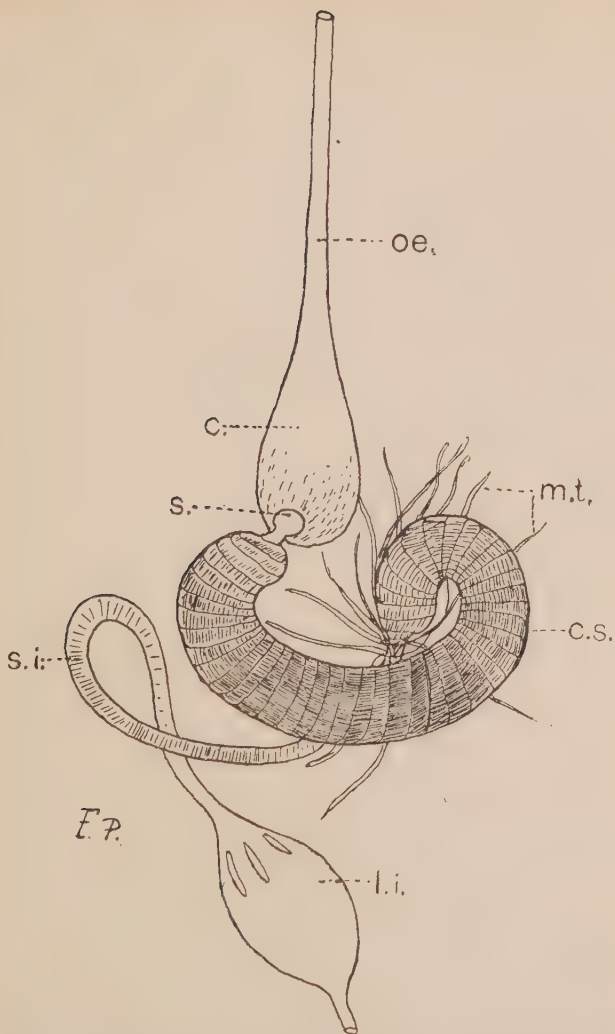


FIG. 42—ALIMENTARY CANAL OF THE BEE. THE DEPTH OF SHADING INDICATES AREAS OF RELATIVELY HEAVY OR SLIGHTER INFECTION WITH NOSEMA APIS

oe., Esophagus ; *c.*, crop or honey stomach ; *s.*, stopper ; *c.s.*, chyle stomach ; *m.t.*, Malpighian tubules ; *s.i.*, small intestine ; *l.i.*, large intestine

excretory organs or Malpighian tubes (Fig. 42, *m.t.*) open into the chyle stomach, but are rarely infected. The hind-gut or large intestine (Fig. 42, *l.i.*) is very seldom parasitized, although its contents may be almost white from the spores contained in it, and under certain conditions, it may contain a fair number of young stages of the parasite, which have come from shed infected cells of the chyle stomach.

All the organs of workers, drones, and queens have been examined in detail for stages of the parasite, but up to the present few developmental forms have been found in them. Again, eggs, larvæ (both freshly hatched and of all ages), pupæ, and young bees, have also been examined. So far as the ovaries of the queen are concerned, while a few planonts have been found very rarely, no further development has been obtained. Larvæ undoubtedly have contained not only young stages, but all stages of the life-cycle of the parasite. But there is always the possibility of larvæ acquiring the parasites with the food supplied them by the nursing-bees or from the "nurses" themselves, and consequently it is impossible at present to affirm that there is hereditary infection.

It is far otherwise with the *Nosema* of the silk-worm. Pasteur's famous method of exterminating pébrine was based on the infection of the eggs by *Nosema bombycis*, acquired from one or other parent. The female moths were so enclosed that the eggs were laid on a pad of cloth. Moths and eggs were given a serial number. The dead male and female were then crushed in water, and the filtered emulsion examined microscopically. If any spores of *N. bom-*

bycis were present in either parent, the remains of the parents and the whole of their progeny were burned. Drastic as this may seem, it was found to be the only means of stamping out the disease; for often the grubs that were born infected would grow well until about to spin, and then extensive mortality would set in and the colony perish miserably. The parasites in these cases remained latent in the bodies of the larvæ for very long periods, but assumed great activity at the time of stress of the host, such activity bringing about not only its own propagation by spore formation, but also the death of its host. Other silkworms which fed in the neighbourhood of an infected larva ate food soiled by the diseased one, and, such food being contaminated with spores of *N. bombycis*, they, too, fell victims to the disease. Both the hereditary and the contaminative methods of infection occur with *N. bombycis*. At present, the latter method, with many variations in its execution, seems to be the only one for the spread of *N. apis*.

The dissemination of the spores of *N. apis*, the only stage proved capable of infecting new hosts, is not only of economic importance, but also presents an interesting example of the reflex of the individual on the life of the community.

It was earlier mentioned that the infected bees endeavoured to the last to fulfil their allotted tasks within or without the hive, and died in the attempt to continue their duties. The fæces voided by such infected bees have been recovered from honey, pollen, and wax in the hive, and from the foliage and flowers

of plants in its neighbourhood—all sources of infection to the still healthy bee.

Bees are cleanly insects, and contact with an infected member of the hive usually has the effect of those concerned becoming spattered with excrement, as is also the hive in their neighbourhood. This defect the bees endeavour to remedy by cleaning themselves, their weakened neighbours, and their hive. The result is that spores are swallowed during the cleaning process, and the very cleanliness of the insects becomes a scourge instead of a benefit.

Drones can become infected as well as worker bees, and infected drones constitute a double danger. They have roving habits, and visit a number of hives indifferently. Probably they are protected by their peculiar odour, for their intrusion into strange hives is very rarely resented. Further, they void fæces within the hive, and when the excrement is removed by the workers, there is danger of them incurring the disease, while there is the probability of the contamination of the food-supply of more than one hive by these infected wandering drones.

When a hive becomes weakened by many deaths, bees of other hives are not slow to take advantage of the fact, and visit the hive in numbers to steal honey. It happens not infrequently that the robbers carry away more than honey; the insidious spores in the honey do their work, and robbers and robbed alike perish.

Wasps also rob hives of honey, and not only that, but they will collect freshly dead or dying bees, and carry them away for feeding their larvæ. We have

known cases where wasps have been exterminated, as the larvæ have succumbed to *Nosema apis*, acquired by a diet of dead bees.

One of the most fertile agents in the spread of *N. apis*, and one that is least under control, is afforded by the drinking-places of the bees. Water is a necessity for bees, especially in the early spring before the honey flow has commenced. Bees prefer water that is slightly warm to that which is colder, even though the latter is far purer. When disease appears in these neighbourhoods, the drinking-places soon become fouled, and the small pools at which the bees prefer to drink are rapidly contaminated with fæces of infected bees, and so become veritable death-traps. When there is a spell of wet weather, the bees will issue from the hives between storms and drink at the nearest puddles. If the soil around the hive has become contaminated, and it usually is, the spores are washed into the tiny pools, and are easily acquired by the thirsty bees. Water is also stored in some cells in the hive, and if infected water is so stored, the brood to whom it is supplied may perish. Much disease among bees can be avoided if readily accessible supplies of pure water are provided regularly for them.

But there is one danger that it is impossible for any beekeeper to guard against. Certain bees have become immune to the effects of *N. apis*, which flourishes within their bodies and produces its spores without apparently causing any discomfort to the insects. The latter live about as long as healthy, uninfected bees, but throughout their lives they are

sowing spores of the parasite broadcast, and producing endless trouble among other bees. Such individuals are known as parasite carriers. Sometimes examination of several hundreds of bees from a hive has failed to reveal any reason for an outbreak of disease; but suddenly a parasite carrier, loaded with spores, has been found, and the mystery is at an end. It is worth noticing that in many cases the bees die as a result of the action of the young (meront) stages of the parasite. So far as the particular bee is concerned, its death brings about the destruction of the parasite, for the young stages are frail and rapidly degenerate, and, so far, have not been shown capable of cross-infection.

Ants and earwigs visit hives to get honey. Should they absorb spores of *Nosema* with the honey, the parasites pass unharmed through their bodies, and are voided unchanged with their fæces. Ants, earwigs, and also wax moths are thus capable of mechanically conveying *N. apis* spores from one hive to another.

The wind also acts as a disseminating agent, and blows the finely powdered fæces containing spores before it, and deposits them elsewhere. Cases are known in which probably the wind has carried infection from hive to hive. At any rate, the spores have been traced in the dust on foliage leading directly from one hive to another, and the dust was only deposited on the distant and lower hive when the wind fell.

Human agency has a share also in distributing disease. Stocks are moved from an infected area

when they show signs of disease. Sometimes this may be done deliberately or sometimes from a mistaken idea that better pollen can be obtained in another locality, and more than one new centre for disease has started in this way.

Then two stocks, both weakened by disease, have been united, with disastrous results, for the increase in numbers means increase of the possibilities for acquiring infection, and both sets succumb. Certainly one set of brood does not get chilled quite so soon if the stocks are united, but the result to the colony usually is as bad in the end, and a recurrence of the disease is often of a more severe nature than the first attack.

Lack of complete cleansing of old hives, again, is a means of continuing disease. Even disinfection with carbolic acid is rarely of much use, and fire seems to be the only effective remedy and means whereby the spores can be destroyed. Slight charring of the interior of the hive is sufficient. Frequently old comb is used, for the labour of wax-production is very great, and should the old comb have come from a diseased hive, it must be regarded with grave suspicion. Small quantities of wax are also collected from various sources, and this is sometimes melted at too low a temperature, and any spores contained therein are unharmed. When the wax is run into troughs for foundation, the spores go with it, and can be easily taken up by the bees.

Preventive measures seem to be of most service in combating the disease. The only certain destructive agent for the spores is fire. All dead bees should

be burned. A painter's lamp should be used over all the woodwork of infected hives before new stocks are placed in them. The soil around infected hives should be removed to a depth of several inches and burned, and the surface should then be limed heavily. It is unwise to unite weak stocks, and also inadvisable to import stocks from a disease-free area into an infected one. The new-comers usually succumb quickly. On the other hand, there is more chance of success if bees from one infected area are moved into another, as there is the possibility that some of them have acquired partial immunity. It seems wisest to destroy all infected stocks as soon as the disease is detected, and, having taken due precautions, to re-stock.

Microsporidiosis has the greatest economic importance in connexion with silkworms and bees, but various members of the Microsporidia are found in other insects and in fish. Among the chief foes of moths and of bees are various Ichneumons, insects which destroy the bee gradually by laying their eggs in the abdomen of the victim. The grubs then develop within the living bee or moth, and ultimately kill it. One of these Ichneumons, *Stenichneumon trilineatus*, is parasitic on the caterpillars of the common gooseberry moth, *Abraxas grossulariata*, but it, in turn, may fall a victim to a newly discovered Nosema, *N. ichneumonis*, which lives in the intestine and the fat body of the adult. This, then, presents an example of hyperparasitism, for the parasitic insect is itself the victim of a protozoal parasite.

It has been suggested that *N. apis* might possibly

be useful in tropical countries, if it could be transferred to insects concerned in the transmission of animal diseases such as trypanosomiasis. Experiments made by us in England have shown that *N. apis* can kill blow-flies, house-flies, sheep-keds, and certain butterflies and moths. But whether the wholesale sowing of *Nosema* would be advisable is very problematic, and in England it certainly would not benefit the citizen who uses honey for food, and keeps bees for profit. Whether it could kill tsetse-flies and be used successfully in tropical Africa for this purpose, remains as yet untested, but is well worthy of trial.

CHAPTER XII

MYXOSPORIDIASIS : SOME OBVIOUS AND SOME CONCEALED DISEASES OF FISHES

PROTOZOA affect man roughly in three ways. The first means by which their influence is felt is when they attack him direct and produce illness of greater or less severity. The malarial parasites, trypanosomes, and Kala-azar parasites are examples of this class. In the second case the Protozoa may affect transport animals and thereby impede commerce. The tick belt for the prevention of the spread of cattle ticks and the presence of trypanosome diseases of horses and cattle in Africa are evidence enough in this direction. The third method whereby the influence of protozoal organisms upon the human race is manifested, is when man's food-supply is endangered by the attack of the parasites on food animals. The Piroplasmata of cattle and the Microsporidia of bees seem, perhaps, to be the attackers of the two extremes in the animal kingdom, with fatal results to each. While the protozoal diseases of cattle are extremely important, it must be remembered that they can be controlled to some extent, and hence the danger from the use of con-

taminated meat can be partially avoided. But a large proportion of the world's population is not mainly meat-eating, and for them there are dangers that are far more insidious. The peoples who eat either little or no meat often partake freely of fish, and fish are attacked by a variety of diseases, some of which have few or no marked external symptoms, while others possess them. Many such diseases are due to minute Protozoa belonging to the Myxosporidia, this group of organisms being nearly allied to the Microsporidia.

The Myxosporidia are extremely interesting. They are small, though giants compared with the Microsporidia, and, like the latter group, are widely distributed, for not only salt and fresh-water fish, but Crustacea also are attacked. The barbel disease of the South of England and Germany, and the trout destruction and pike devastation of Germany and many parts of France, are still events within the memory of the present generation, and Myxosporidia were the agents of extermination in each case.

Myxosporidia, like Microsporidia, are sometimes restricted to one organ of their host, while in other cases they diffuse gradually throughout the body of the animal infected. Naturally, the tissue parasites have much the more obvious effects on their hosts, but it is quite inaccurate to suppose that the parasites found within the body cavity, urinary bladder, or gall-bladder of a fish, seemingly free-floating, are non-injurious. Such is far from being the case, for changes are introduced into the metabolism of the animal, sometimes with very grave results; and, on

the other hand, it must be remembered that any parasite of an animal that utilizes even the smallest portion of food destined for the nourishment of that host is depriving the latter of its nutriment to the extent of the food absorbed. Hence it is really incorrect to speak of any parasite as harmless or blameless.

The majority of the Myxosporidia possess a somewhat massive protoplasmic body when full grown, and within the body at any stage of its life either two large spores or many small spores are produced. The number of spores formed has been used as a basis of classification, and the groups Disporea and Polysporea result. The spores are the means of continuing the life of the organism. They possess a complicated structure which will be detailed later, but from each one a small amœbula issues when the spore is favourably situated. This occurs in the case of fish parasites, when the spores swallowed with food or water enter a new host, and the digestive juices found in the intestine act upon the spore coat, or sporocyst. The amœbula may enter a cell of the host's food-canal, or may pass into the diverticula of the food-canal, sometimes reaching the gall-bladder. Perhaps by way of the blood-stream it may reach the urinary bladder of the host, or, as in other cases, it can attack the musculature and even the nervous system. Wherever it penetrates, the course of development is much the same. The parasite increases greatly in size, and during its trophic existence feeds passively to a large extent on the semi-fluid media by which it is surrounded. While

so engaged it is not inactive, but is capable of moving by pseudopodia over the surface of the cavity containing it, or in and between the cells by which it may be surrounded. Parasites lying in the gall or urinary bladders of fishes form temporary attachments for themselves by means of their pseudopodia, and there is no doubt that these pseudopodia are not merely organs of attachment, but also are organs of absorption. We, ourselves, have seen food currents from invaded cells pass into the pseudopodia, and when sections of the infected gall-bladders of certain fishes such as the pollack are examined, the great deformity of the cells is evidence of the action of the parasites.

When tissues are infected, softening sometimes occurs ; at others, hard lumps form beneath the skin. One kind of Myxosporidia infests the gills of certain fishes, where it forms hard lumps that interfere considerably with the aeration of the gills. Another member of the group produces excrescences on the nerve roots of its host. Yet another invades and liquefies the muscles of a large, pikelike fish used extensively for food in Australia, especially in New South Wales and Queensland. The infected fish are, however, sold in the open market, and the poorer members of the community suffer, as "milky Barracoutta," or "Barracuda," is avoided by all who can afford to do so. The exudate from the disorganized musculature of the fish resembles milk, and owes its colour to the numbers of myxosporidian spores present in it. The special organism in this case is known to be a *Chloromyxum*.

The exact time at which reproduction of the Myxosporidia occurs is uncertain, but it may be stated generally that cold weather is favourable to spore formation, while warm weather tends to prolong the purely vegetative phase of the organism's existence. The details of the processes leading up to spore formation vary slightly in the different genera of the group, but there is a general type of structure that prevails in all. Within the body of the trophozoite one or more portions are differentiated for reproduction. Each portion possesses a definite nucleus, and its cytoplasm gradually becomes distinct from that of the rest of the body. These specialized portions are the pansporoblasts, or spore progenitors. Sometimes they occupy a fixed position in the cell; at other times, especially when more than two are present, their positions are very varied. Zonal arrangement is known in some.

Each pansporoblast at first is uninucleate, but its nucleus divides rapidly to form either two or several nuclei, so that the pansporoblast becomes multinucleate. Each division or sporoblast secretes a cell wall around itself. This cyst wall, or sporocyst, is distinctly bivalved and a clearly marked sutural line is present. The spore is thus produced. It, too, is multinucleate. Two nuclei control the formation and regulate the movements of the valves. They are variously termed the parietal, valvular, or sporocyst nuclei. Within the sporocyst two vacuoles develop, or in the Chloromyxidæ four are produced. These may lie side by side, or may be at opposite poles of the spore. Their positions are points used

in classification. Within each vacuole a long, coiled filament is formed, capable of ejection and used for fixation. For the regulation of each polar filament with its polar capsule or vacuole a nucleus is set apart. This latter is the capsulogenous nucleus. Four capsulogenous nuclei occur in the *Chloromyxidæ*, two in the other members of the group. The general cytoplasm of the spore also is provided with a nucleus, which may divide again, so that the sporoplasm is binucleate.

The appearance of the spores is very varied in the different groups. The members of one large genus, *Myxidium*, have very characteristic lemon or lens-shaped spores. *Ceratomyxa* has flattened, elongate spores, often with long processes or tails. The *Leptotheca* spores are oblong and squat. *Chloromyxum* may have remarkable patternings and foldings of its sporocyst. *Sphæromyxa* has narrow, curved spores. The spore of *Henneguya* is remarkable for its long, narrow tail, and is suggestive of a tadpole; while *Hoferellus*, from the kidney of the carp, bears some slight resemblance to a skate's egg, devoid of coils (the "mermaid's purse" of the sea-shore).

As previously mentioned, there are two great divisions of the Myxosporidia, and pathogenic genera are found in each. The Disporea possess two genera, *Leptotheca* and *Ceratomyxa*, while the Polysporea embrace seven genera—*Myxidium*, *Sphærospora* with *Sphæromyxa*, *Chloromyxum*, *Myxobolus*, *Lentospora*, *Henneguya*, and *Hoferellus*. Among these genera, so far as destructiveness has been concerned,

the genus *Myxobolus* has been most identified with disease, and has been responsible for exterminating

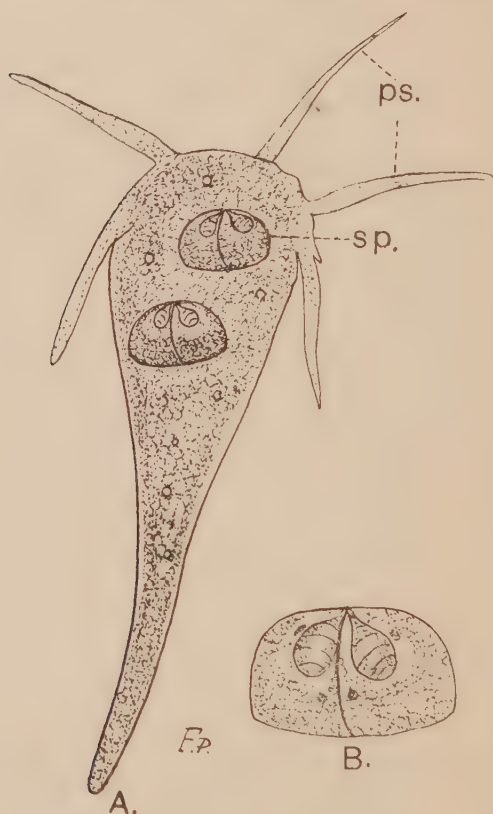


FIG. 43 — LEPTOTHECA, FROM THE GALL-BLADDER OF THE MACKEREL

A, Trophozoite containing two spores. *sp.*, Spores; *ps.*, pseudo-podia

B, One spore, showing its two valves, sporoplasm, and two polar capsules

fish both in England and on the Continent, barbel, trout and carp being more especially its victims.

The genus *Leptotheca* (Fig. 43), like most of these organisms, shows great polymorphism in its trophozoites. The most characteristic appearance of them occurs during movement, when a number of long, narrow, filamentous pseudopodia are given off (Fig. 43, A, *ps.*) and trail usually behind the greater part of the body mass. The main cytoplasmic structure is more or less conical, and when fresh material is examined, the protoplasm appears filled with shining yellowish droplets, probably produced from the bile absorbed by them, for *Leptotheca* lives in the gall-bladder of certain fishes. During early growth, two nuclei are present, but ultimately ten are formed, five being utilized for each of the two spores produced (Fig. 43, A, *sp.*). The spores of *Leptotheca* (Fig. 43, B) are broader than they are long, being 5 to 6 μ long and 6 to 7 μ broad. The mode of transmission of the parasite from one host to another was unknown till recently, but the present authors have established that the method of infection is contaminative. A species of *Leptotheca* was observed by us from the gall-bladder of the mackerel. The spores of this parasite have been traced through the alimentary canal and into the fæces, which, when voided, contaminate the water and thus are so situated as to be readily absorbed by other fish, especially as they swim in schools.

The genus *Ceratomyxa* is also a parasite of marine fishes. It is remarkable for its polymorphism. The species that we have investigated from the bile of the

shark, *Galeus canis*, shows numerous forms of trophozoites, varying from subspherical to most extraordinarily irregular bodies. The spores of some species are prolonged laterally and form long horns (Fig. 44, *c*), while in others no such appendages are present. Wherever the spores occur, their extreme fragility is a matter of comment. Sometimes they attain a breadth of $32\ \mu$ and a length of $6\ \mu$. Their polar capsules are adjacent to one another, but on opposite sides of the valvular suture (Fig. 44, *d*).

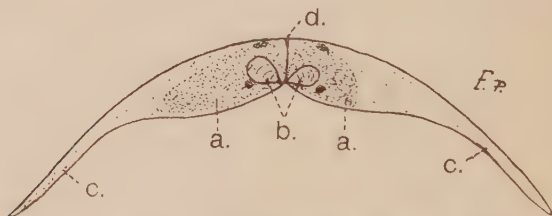


FIG. 44—*CERATOMYXA*: SPORE FROM BILE OF *GALEUS CANIS*

a, Sporoplasm; *b*, pole capsule; *c*, horns of spore; *d*, suture. In this species the two halves of the spore contain unequal quantities of sporoplasm

Sometimes the sporoplasm is unsymmetrically arranged. Such is the case with the spores of a new species of *Ceratomyxa* (Fig. 44, *a*) occurring in the gall-bladder of *Galeus canis*, though symmetry occurs in the forms found in *Crenilabrus*, the gold sinny, and *Labrus*, the wrasse. The wrasses we have examined in North France and in England do not seem to be parasitized, though they are often reported to be so in South France. While the parasite was formerly considered to be harmless, this is now known to be an erroneous opinion, the para-

sites of the tope, shark, and the various wrasses being deleterious to the hosts.

The Polysporea are much more important economically than are the Disporea. This is not surprising, for the faculty of producing numbers of spores instead of two only gives increased chances of transferring the infection from host to host. It also ensures the perpetuation of the species to a much greater extent than when two spores represent the limit of the reproductive capacity of the trophozoite. The power of inflicting damage upon their hosts seems more intense among the Polysporea than among the Disporea. Their power of movement is greater, their pseudopodia frequently seem more abundant, and many have a purely vegetative method of multiplication in addition to spore formation. A large species of *Myxidium* is a common parasite of the urinary bladder of the pike. Its spore formation occurs during very cold weather, and it is not commonly seen in England. But an infected pike can be recognized almost at once, for its urinary bladder is flecked and streaked with yellow patches, which show through the thin-walled organ. These flecks may become so numerous in later stages of the infection that they show as a continuous slimy layer over the entire inner surface of the bladder. This slimy layer consists of innumerable trophozoites of *Myxidium lieberkuhni*. These trophozoites bud in a remarkable fashion, and the general protoplasm contains a large number of nuclei, some of which pass direct into each bud. The buds gradually become separated and pass away as new small

trophozoites, growing and feeding passively within the bladder of the host. Reproduction of this form is termed plasmotomy, and has been best investigated in the genus *Myxidium*. The Polysporea can be discussed best in three main groups, and certain members of these groups are responsible for many destructive outbreaks among fish, both fresh-water and marine.

The first group, the Myxidiidæ, are fairly near to the Ceratomyxidæ. The Myxidiidæ are more particularly known as cavity parasites, though some occur in tissues. They cannot be said to be highly pathogenic to the host, nor in many cases are there external indications of the occurrence of the parasite within. The parasites are separated into two main genera: (1) *Myxidium*, with several species, and (2) *Sphærospora*. Both are alike in having a very distinct ectoplasm and endoplasm, the latter being highly charged with granules, some of which are ectoplasmic, while others are yellowish and are probably excretory in nature.

The parasite *Myxidium lieberkuhni*, from the urinary bladder of the pike, is one of the best known. The pathological effect of the parasite upon its host does not seem to have been investigated as completely as it needs. The trophozoites are large and propagate by direct budding (plasmotomy), as before mentioned. Many examples can be found that never show spores, but old specimens sometimes show numbers of the somewhat spindle-shaped spores which possess a capsule at each end. They are 18 to 20 μ long, and 5 to 6 μ broad.

The present authors have investigated species of *Myxidium* (Fig. 45) from the gall-bladders of *Gadus pollachius*, *G. merlangus*, *Cottus bubalis*, *Raja batis*, *R. maculata*, and other fishes, and so far have rarely seen continued or simultaneous plasmotomy. The formation of buds appears to have been more isolated

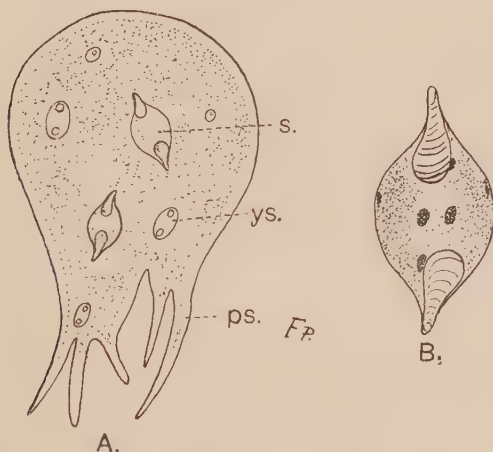


FIG. 45 — MYXIDIUM FROM THE GALL-BLADDER OF *GADUS MERLANGUS* (ALLIED TO THE COD)

A, Trophozoite of Myxidium. *ps.*, Pseudopodia; *s.*, spore; *ys.*, young spore

B, A single spore of Myxidium stained, much enlarged. Polar capsules with filaments inside, two sporoplasmic nuclei, polar capsule nuclei, and remains of valvular nuclei seen

than in the case of the pike parasite. In the above fishes the epithelium of the gall-bladder is often directly attacked by the parasites, which sometimes lie deep within it, but more often with their pseudopodia (Fig. 45, A, *ps.*) penetrating it for a considerable distance, and at times even reaching the

submucosa. The spores of the *Myxidium* in the above marine fishes at first are rounded and uninucleate. They then become elongate and oval (Fig. 45, B). The nucleus multiplies, and gradually two valvular nuclei are produced, under whose influence the two valves of the sporocyst appear, while simultaneously two other nuclei control the formation of the two polar capsules. These latter structures at first appear as tiny oval or rounded refractile spots (Fig. 45, A, y.s.). They increase in size and refractivity for some time, and gradually become ovoid. The polar filament forms and often protrudes slightly from the capsule. The polar capsules are not exactly opposite one another, and this slight asymmetry is marked by the protrusion of the end of the filament, the ripe spore presenting an appearance very like that of a lemon.

The method of infection has also been shown experimentally by the same workers to be by the contaminative method—by the mouth. Bred fish from known clean stock have shown intense infection in about three weeks after feeding on food contaminated with the spores of the *Myxidium*, taken either from the gall-bladder or from the excrement of an infected fish. The spores are passed through the alimentary canal unchanged until they reach the junction of the pyloric cæca and the intestine, and there the powerful digestive ferments cause the opening of the valves, and the contained amœboid germs escape to pass up the bile-duct into the gall-bladder, where they grow for a time and then proceed to form spores.

The expulsion of the spores from the body of the trophozoite has been seen on several occasions. The spores are forced forwards towards that part of the body where free pseudopodia occur (usually at one end). The forward pressure is renewed as the spores reach the pseudopodia, and as there is less resistance at those spots, the spores glide forward and pass through the ectoplasm between the pseudopodia. These latter structures tend to push the spores onwards until they are well away from the neighbourhood of the parent trophozoite.

The various species of *Myxidium* investigated by the present writers cause great changes in the gall-bladders and bile of their respective hosts. The epithelial lining of the organ becomes ragged, and the fibro-muscular layer beneath becomes so enlarged that the wall is rendered quite opaque, in marked contrast with the thin, transparent gall-bladder of the uninfected fish. Normally, the bile of fishes contains a large quantity of fat. Such is the case with healthy pollack, merling, whiting, etc., that we have examined. Further, the bile is limpid, bright green, and very clear. In contrast, in an infected fish the fat content of the bile is much decreased, the viscosity due to the formation of much mucus is enormously increased, so that the bile is often like a stiff jelly or thick purée, and the range of colour varies from orange to dirty white, owing to the action of the parasites on the chemical composition of the bile. It should be mentioned that all the *Sphærospora*, *Ceratomyxa*, and *Chloromyxum* investigated had a similar effect upon the bladder and the bile of their

hosts. The genus *Sphærospora* in many respects is like *Myxidium*, but it has a spherical spore and its two polar capsules lie side by side. *Sphæromyxa* (Fig. 46), a genus founded by Thélohan, is also nearly allied to these forms, and has a similar trophozoite structure, but forms long, curved spores. These parasites may form but few spores at a time, but on occasions numerous spores can be seen within them.

Before leaving the family Myxidiidæ it should be mentioned that while these organisms have definite

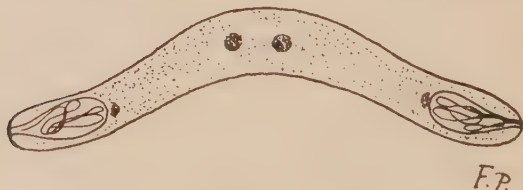


FIG. 46—SPORE OF SPHÆROMYXA: SUTURAL PLANE HORIZONTAL.
FROM THE GALL-BLADDER OF A BLENNY

pathological effects on the marine fish, among which they are widely distributed, yet they can be equally injurious to fresh-water ones. A recent epidemic in the West of England among dace and trout has been traced to the agency of a *Myxidium* in the gall-bladder, and an allied species is responsible for the death of golden carp, the gall-bladders of these fish also being the seat of infection.

The genus *Chloromyxum* (Fig. 47) possesses a special interest in that it occurs not only in the gall-bladders of several fishes of the shark group (Selachii), but also in the muscles of certain

Australian fishes. Its structure and modes of propagation also have a distinct interest, for its trophozoite is loaded with pigment (Fig. 47, *p.*), and not only is spore formation common, but fission also occurs. The trophozoites contain numerous granulations, sometimes rounded, sometimes irregular. They are distributed throughout the cytoplasm, and vary in

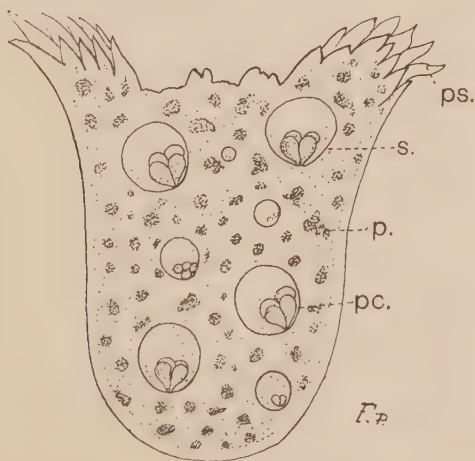


FIG. 47—TROPHOZOITE OF CHLOROMYXUM

ps., Pseudopodia ; *s.*, spore ; *p.c.*, polar capsules ; *p.*, pigment masses

colour from yellow to almost green (Fig. 47, *p.*). The exact nature of the colouring matter is not known, but the pigment is in some cases perhaps derived from the tissue or fluid in which the organism lives. The spore (Fig. 47, *s.*) contains four polar capsules instead of the usual two (Fig. 47, *p.c.*).

Chloromyxum has been generally regarded as a

relatively harmless parasite when it was found in cavities such as the gall-bladder. As with other members of the Myxosporidia, the belief in its harmlessness was misplaced, for its presence causes digestive derangements, renders the wall of the bladder very much thicker and less elastic, and by interference with nutrition causes emaciation, as shown by loss of weight.

The Myxobolidæ are probably the family of the Myxosporidia to be most dreaded by the fish-stocker and sportsman. Many of the members are tissue parasites, and are pathogenic to the animals harbouring them. Sometimes they form large masses that block the kidney tubules of their hosts; or they may form diffuse masses penetrating throughout the body of the victim. They have very varied forms of trophozoites, much depending on the size and shape of the cavity in which the parasite is found. Similarly, the number of spores produced by any one trophozoite varies; but it is characteristic of the Myxobolidæ that they form two pear-shaped polar capsules at one end of the spore.

The genus *Myxobolus* is more particularly a parasite of fresh-water fishes. The pike, carp, tench, barbel, trout, roach, and chub, among others, are badly infested, and the barbel has become practically extinct in many waters as the result of the infection with a *Myxobolus*. In the case of the barbel, the carp, the trout, the roach and chub, there is external evidence of the disease in the form of numerous and tumour-like swellings on the skin. These may be relatively soft, or, as in *Cyprinodon*

variegatus of North America, chalky secretions occur intermingled with the spores.

The barbel disease is due to *Myxobolus pfeifferi*. The external features consist of discoloured patches on the skin, and large, lumpy tumours sometimes reaching the size of a fowl's egg. The parasite has small trophozoites which may confine themselves to the kidney tubules of the barbel, or may diffuse throughout the connective tissue of the kidney, liver, spleen, and musculature. Even the genital organs may become heavily charged with parasites. No part seems absolutely immune. When the parasites lie between the muscle fibres, the tissue endeavours to shut



FIG. 48—SPORES OF A MYXOBOLUS FROM A MUSCLE FIBRE OF THE BARBEL: TRANSVERSE SECTION

off the parasite, and great thickening occurs in its neighbourhood, so that a structure resembling a worm cyst is produced. Within this capsule the trophozoite develops an enormous number of spores, and finally perishes, leaving its own degenerated body and the degeneration products of its activity, together with the spores to fill the space it originally occupied.

The spores are very small egg-shaped bodies with

two clear polar capsules (Fig. 48). They are washed out from the body of a dead fish in great numbers and with ease; and as the infected fish decays in the water, so does the plague spread. When epidemics have arisen, the only possible remedy has been to net the stream where any dead fish has been seen, and to destroy ruthlessly any one exhibiting the slightest trace of skin tumours. Destruction by killing is not enough; the corpses must be burned, and not buried or left to decay in the air, as the spores could again reach the water under the action of wind and rain.

The disease described as "smallpox" (Pockenkrankheit) of the carp is due to the action of *Myxobolus cyprini*. The external appearance of the infected fish resembles that of the barbel, but there is a very great difference between the two sets of tumours seen on the skin. In the barbel the tumours consist of disintegrated tissue and numerous trophozoites and spores of the parasite; but the swellings on the carp are secondary results of the action of *Myxobolus cyprini*. They consist of an enormous number of colourless blood-corpuscles which have filtered into the epidermis and the layers beneath it, and have formed a mass of tissue there, mingled with some red cells of the blood.

The young stages of the parasite occur in numbers in the epithelial cells lining the kidney tubules, and thereby interfere considerably with the excretory function of these organs. They increase in size, and subsequently rupture the epithelium, so reaching the channel of the tubule, which soon becomes blocked

with their bodies and spores. Some of the tubules retain the power of excreting sufficient liquid to wash out some of the spores, which find their way then into the excrement and mingle with the fæces, whence spores can be recovered. As the number of spores is very great, and as each trophozoite produced therefrom has enormous potentialities of further spore production, one diseased fish can easily infect a considerable area of water by means of its evacuations, while the decay of one dead carp means the release of innumerable spores in a short time. A certain amount of discussion has arisen as to whether or no *Myxobolus cyprini* is the true cause of the carp disease. But while other agencies have been suggested, nothing has been proved except that *Myxobolus cyprini* can cause the skin disease and death of the host. The idea that *M. cyprini* was not deadly arose partly from the view that many of the Myxosporidia were non-pathogenic, and analogy was used instead of fact. Another *Myxobolus* occurs in the nerves and spinal cord of brook-trout, to which it causes injury.

The second genus of the Myxobolidæ is the *Lentospora*, members of which are responsible for deformities in the skeleton of certain Salmonidæ and the cartilaginous parts of such fishes as the cod and whiting. The balancing organs, which form part of the ear, may become infected, with the result that the fish cannot maintain their equilibrium. In fact, they may be said to suffer from "fish staggers." The cartilaginous parts of the skeleton are attacked chiefly, but as the membranes that nourish the

gristle and bone also become diseased, these latter cannot grow much. Movement also is hampered, for the skeleton of the fins, as well as of the head and tail, is commonly affected. *Lentospora* is far more dangerous to young fish than it is to older ones whose skeletons have become more developed.

The parasite itself is much like a *Myxobolus*, but its rounded spore emits an amœbula which differs from all other *Myxobolidæ* in lacking a vacuole that stains with iodine. The trophozoites are large, but owing to their situation are not noticeably motile. Apart from the lack of the iodophilous vacuole and the remarkable situations in which the organisms occur, there is little to distinguish them from the *Myxobolus* proper.

The third genus of the *Myxobolidæ* is known as *Henneguya*, and while its members occur chiefly on the gills of fish such as the perch and popefish (*Acerina*), some of its members are able to penetrate the eggs and form cysts within them. The spores of *Henneguya* are oval, but possess a long, whiplike but rigid appendix at the end opposite the polar capsules.

The fourth genus, *Hoferellus*, occurs in the kidney tubules of carp, sometimes in association with *Myxidium*. The organism possesses rather remarkable spores with short horns, somewhat the shape of the egg-case of a dogfish. The sporocyst is striated longitudinally, and the two polar capsules are at one end. It is stated that *Hoferellus* rarely blocks the kidney tubules, but occasionally stoppage of an individual tubule is found.

The Myxosporidia have now been discussed briefly, and, in closing, it would be well to sum up their rôle as agents of disease. When large tumours containing parasites are present, the action of the organism is obvious, but where there are no external manifestations, the results must be determined by other means. One of the best guides to the condition of an animal is its weight, and loss of weight coincides with the presence of Myxosporidia. Digestive and excretory troubles also are accompanied by emaciation. Loss of fat is general. Some cases show marked malformation of the bones and of the cartilage. Breathing also may be impaired, and then anæmia results. The worst effects are seen in the cases of diffuse infiltration, when no organ is safe from the attacks of the parasite.

What, then, can be done to remedy this state of affairs, and how can myxosporidian infection be stamped out? Deep-sea fishes certainly number many victims, but it is obviously impossible to apply remedial measures to them. All that can be done in that case is to burn any infected fish taken, and endeavour to keep the main feeding-grounds of fishes as clean as possible.

Fresh-water and partly fresh-water fish, such as the Salmonidæ, are more easily subjected to experiment, for the trade of fish-breeding has now reached a high state of perfection, and hatcheries have sprung up in many places. At such institutions two evils may arise—namely, overcrowding and inbreeding, and both are conditions favouring myxosporidiasis. Overcrowding involves ingestion of spores from the contami-

nated water in which the animal is living. Inbreeding tends to intensify any weakness, and thus allows of fiercer attack by the parasite. Again, among artificially hatched fish there is rarely the competition or struggle for existence such as naturally hatched fish undergo, with the result that weaklings survive and even reach maturity, which would never occur under natural conditions. Hence when outbreaks of disease occur in artificially stocked waters, the rate of mortality is much higher than among "wild" fish. At the same time, should the epizootic occur in the hatchery, there is the possibility of adopting rapid disinfection measures and of spore destruction, such as is hardly possible in the open.

Every year the newspapers report cases of mysterious deaths among fish. Pollution from factories, road tar, sheep dips, etc., are blamed. Disease is not often suspected, and still less are any active measures taken to suppress the outbreak. As before mentioned, dead fish should be collected and burned wherever possible. The drastic remedy of completing the destruction of the fish by draining off the water and then exposing the bed to light and air for some time, and also lime-dressing it, is most effective, but is rarely practicable, on account of the cost and labour involved. The netting of streams and ponds and destruction of all suspects are far from being so difficult as drainage, nor are they so efficient, but they are very useful in combating any outbreak. Chemical treatment, such as spraying with petrol or paraffin, may help in destroying myxosporidian spores; but the amount of damage done to the larvæ

of insects, minute Crustacea, etc., that form a considerable proportion of the food of fishes, apart from the harm to the fish themselves, is incommensurate with the amount of success achieved in combating the disease. The remedy is often worse than the complaint when the utility side is considered.

Finally, the use of tonics in water has been suggested, some form of iron salt being the most favoured. While undoubtedly iron salts are tonics, and of use in combating anæmia, it is almost impossible to utilize them on a large scale. Water currents, decomposition due to other chemicals, dislike of medicated waters by the fish themselves, all tend to defeat such attempts at curative methods, and force the conclusion that, here as elsewhere, the health of the fish population is to be maintained by strict attention to preventive measures, rather than to treatment once the disease has manifested itself.

CHAPTER XIII

PARASITIC CILIATES

THE Ciliata are among the commonest occupants of any small patch of stagnant water or decaying, moist vegetation, and some of the most beautiful of the Protozoa occur in this group. Many Ciliates exist as free-living organisms. There are relatively few parasitic forms of Ciliates known, and they are not associated with any markedly deadly complaint, with few exceptions.

The body of Ciliates varies greatly in appearance. Some are sessile, some stalked. There is every shade of gradation between the most graceful, bell-like *Vorticella* or *Carchesium* and the flattened, leaf-like degenerate *Opalina*, but all alike possess external outgrowths of the body wall, known as cilia, by which they move. Most of them also have two nuclei (Fig. 49, *a*, *b*)—a large one, or macronucleus, which is entirely trophic in function, and a small one, or micronucleus, of a totally different nature, since it is concerned solely in reproduction.

The body surface in many cases has the cilia arranged in regular rows, and examination shows that the vibratile threads follow the lines of con-

tractile elements in the ectoplasm, known as myonemes, or myophan striations. The cilia normally move fairly slowly and regularly, creating a definite current, generally towards the mouth. Certain of the cilia are much longer than others, and move more rapidly, and these have been seen entangling food for the Ciliate and propelling it towards the mouth. Such longer cilia are sometimes termed cirri. Again, the cilia in some cases are so close that they unite together and form a continuous structure like a membrane. The appearance of some members of the Ciliata in which the membrane is well developed is suggestive of some remarkable flagellate at times, but some free cilia are always present.

The free-swimming Ciliates living in fresh or salt water are remarkably active. They move quickly by means of their vibrating cilia and myonemes, and can turn round rapidly. One end always is directed forwards. This—the anterior end—often contains the cell mouth, or cytostome, which varies greatly in form. A free-swimming form like *Paramæcium* has a funnel-shaped side aperture prolonged into a narrow gullet, or cytopharynx, lined with cilia which waft food particles inwards. The cytostome in a form like *Enchelina* is small and slitlike, and capable of opening and closing. During “feeding times” the boundaries act as lips, and open for the introduction of food; then during digestion they are closed so that the orifice is practically obliterated. An interesting parasite from the cæcum of the horse, *Blepharocorys* (Fig. 49), has a mouth overhung by

a sort of hood (Fig. 49, *e*), which is raised for the purpose of absorbing food particles. The cytostome in the free-living forms is beset with cilia along its entire circumference, but some parasitic forms show

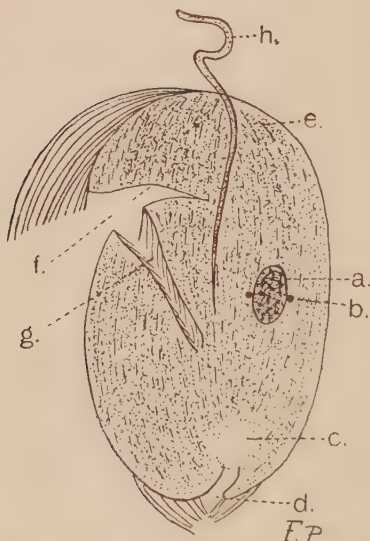


FIG. 49--BLEPHAROCORYS, FROM THE CÆCUM OF A HORSE

a, Macronucleus; *b*, micronucleus; *c*, contractile vacuole; *d*, anus fringed with cilia; *e*, hood overhanging the mouth, with fringe of cilia; *f*, mouth; *g*, gullet with cilia along it; *h*, the adhesive filament

restriction. In *Blepharocorys*, for instance, tufts of cilia overhang the mouth, and undoubtedly aid in sweeping food particles into the cytopharynx, while an outwardly directed tuft serves to waft waste food particles from the cell anus or cytopyge (Fig. 49, *d*).

Blepharocorys is less parasitic than certain other Ciliates, for it is able to obtain some of its food by active movements initiated by its own cilia. *Opalina* (Fig. 53), found in the rectum and bladder of the frog, has undergone

further reduction of structure. It can no longer create food currents in a particular direction, and waft nutritive particles towards a specialized region of the body. It possesses cilia, but these are equal

in length, and evenly distributed. Their function has become locomotory only. A further simplification is seen in that *Opalina* has no mouth and no anus. Its nourishment is obtained by absorbing fluids around it by its entire body surface.

The cell gullet, or cytopharynx (Fig. 49, g), is large in free-living Ciliates, and is reduced in parasitic ones. A cell anus is present in some cases, but it is remarkable that in some of these organisms occurring in cattle there is a well-marked anus, and yet no mouth is present. In many Ciliates the intake of food is accomplished at a cytostome. Various food particles are surrounded by small quantities of fluid forming food vacuoles, and the vacuoles circulate through the body in a definite direction. When all the nourishment has been absorbed, each particle of débris is diverted from the circulating area and pressed from the body at any point if no cytopyge is present, or passes from the regular channel if such is available. In a small Ciliate parasitic in pond snails we have been able to watch the intake and digestion of food and the expulsion of the waste matter, the latter occurring through the mouth, a most unusual circumstance.

The two nuclei of Ciliates have already been mentioned. The macronucleus is usually very large, and frequently is curved. In some organisms (*Spirostomum*, *Stentor*) the macronucleus is beadlike. Alterations in the shape of the nucleus occur in some species, and it can move from one part of the body to another. The micronucleus, when present, is small, and divides during reproduction. In some

cases its presence has not been proved, but it is always minute, and during some phases of the life-history of the organism is not easily detected.

A conspicuous feature of some members of the group is the contractile vacuole. While some Ciliates have but one vacuole, usually two or more are present. They contract rhythmically, and collapse instantly when they reach the surface. The vacuoles may occur at any position in the organism, but the vacuole of *Blepharocorys* (Fig. 49, *c*) discharges direct into the anus.

Defensive structures are not common among the Protozoa as a group, but they are present in the free-living Ciliates and to some extent in the parasitic ones. The outer layer of the body has a series of small pits in it, and within these pits are threads which can be discharged when necessary. They seem to be both defensive and of use in food capture. *Blepharocorys* has a long filament (Fig. 49, *h*) used generally for attachment, but possibly defensive.

Multiplication among Ciliates is abundant. Many of them simply divide by binary fission over and over again, until an enormous number of generations have been accomplished. This asexual reproduction is accompanied by decrease in size, and after a time the daughter organisms become enfeebled and may lose entirely the power to continue division. Generally, before this occurs two individuals form a temporary association for the purpose of exchanging micronuclear material, the result of which is to revitalize both members, enable them to attain full size again, and once more propagate by division. It

was partly from observation of these phenomena, which can be repeated for a long period, that the old idea of the immortality of the Protozoa arose.

The two individuals that associate may be different sizes or alike. They attach themselves, side by side, and while free-living forms can and do swim about actively when in association (or conjugation), the parasitic forms rarely do so. The large macronucleus of each gradually disappears, while the micronucleus increases in size and commences to divide, and the division is repeated until usually four or eight nuclei are produced. All of these save one in each conjugant are absorbed and disappear. The one remaining divides into two, and of these, one remains stationary, the other migrates towards the second conjugant. The cuticle between the two organisms now disappears, and the migratory nucleus of each associate passes over into the other and fuses with its stationary nucleus. The cuticle then re-forms, and the two organisms separate. Soon after, the new nucleus divides into two, one of which becomes large and forms the new macronucleus, while the other remains small and is the micronucleus. Growth continues, and soon the organisms are indistinguishable from the ordinary individuals of the species, and take up again their old vegetative life.

While it is true that the Ciliates are among the most beautiful microscopic organisms, and the majority of them are quite harmless, yet others are associated with diseases both of human beings and of other vertebrates. Dysentery is due to many organisms, perhaps the most serious trouble arising from

bacteria and amœbæ. Ciliates take their share in its production, for two species each of *Balantidium* and *Nyctotherus* have been found in association with the malady. The *Balantidium* is perhaps the more common, and more is known about it, so it will be described first.

Balantidium coli (Fig. 50, A) is the larger of the

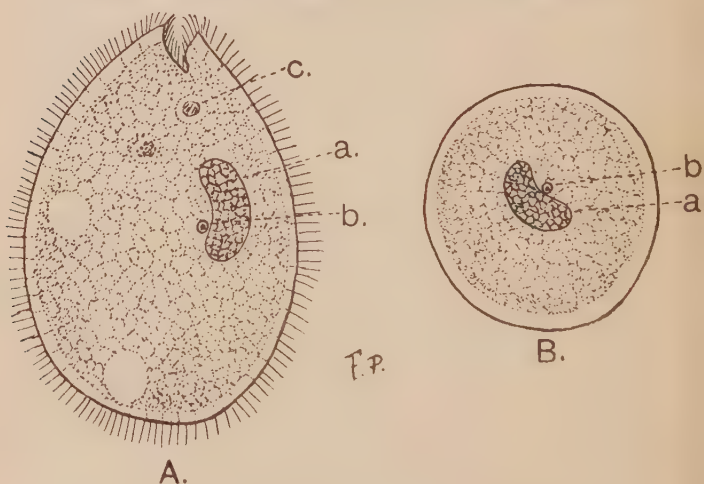


FIG. 50—BALANTIDIUM COLI

A, Large free ciliate; B, rounded cyst of *B. coli*, from the faeces of the pig

a, Macronucleus; b, micronucleus; c, food particle

two species occurring in man. It is about $\frac{1}{16}$ mm. long, and the body is oval. If the mouth and gullet are contracted, the anterior end of the organism is more pointed than when they are relaxed and open. The body is covered with parallel rows of cilia. The macronucleus (Fig. 50, A, a) is large, and is

bowed or kidney-shaped, and a small, spherical micronucleus (Fig. 50, A, *b*) is somewhere in its neighbourhood, often in contact with it. The organism possesses two contractile vacuoles for the excretion of liquid waste, but no permanent cell anus exists. When the *Balantidium* is removed from the intestine, it often contains numerous drops of mucus, and sometimes red blood-corpuscles have been seen within it. The multiplication is brought about by simple division of the free forms into two, and the division is not repeated until these two are full grown. At times conjugation occurs. Spherical thick-walled cysts (Fig. 50, B) also are formed, and with motile forms are found in stools of dysenteric patients. Balantidian dysentery at one time was common in the Philippine Islands, where amœbic dysentery also was rife, and they still occur there.

Balantidium coli is a constant parasite of pigs, in which it does not seem to do much injury, but from the pigs it can reach man. Numerous cysts are found in the pigs' excrement, which is used in the cultivation of the land. The cysts thus get scattered, and can contaminate both water-supply and vegetables and fruit, whence the parasites reach man. If the recipient of the cysts is thoroughly healthy, no harm may accrue. But if the intestine be at all deranged, the parasites produce further irritation and penetrate the epithelium and lie in the layers below it, looking very like *Entamoeba histolytica*. It is of interest to note that some strains of *Balantidium coli* are less virulent than others. *Balantidium minutum* is about one-fifth the size of

B. coli, and possesses a larger cytopharynx. It seems to be a much less common parasite than *B. coli*.

Nyctotherus is a genus of Ciliates with bean or kidney shaped bodies, possessing a large, curved cytopharynx. *Nyctotherus faba* and *N. giganteus* have been found in man, but many have been described from the intestines of Amphibia and insects. *N. faba* (Fig. 51) is about $\frac{1}{10}$ mm. long, and



FIG. 51—NYCTOTHERUS FABAE

The Ciliate as it occurs in man

has fine ordinary cilia on one side of its mouth, and thick forms (cirri) on the other. *N. giganteus*, which has been found in the dejecta of typhoid patients, may be as much as $\frac{2}{5}$ mm. long and $\frac{3}{20}$ mm. broad. It encysts in the fæces, and each new cyst produces four new parasites.

Probably one of the most interesting Ciliates, at least to the fisherman, is the fish parasite, *Ichthyophthirius*. The organism is probably of more trouble to the owners of aquaria or fish hatcheries than it is in the open, but even there it has been known to do much damage, especially in heavily stocked waters. Wherever the fish are collected in numbers, then the mortality increases by leaps and bounds should a single specimen infected with *Ichthyophthirius* be introduced. It attacks

fish, more especially fresh-water fish, indiscriminately, but is more especially associated with Cypriinoids, such as carp, the Salmonidæ, pike and perch, and flourishes equally well in any of them.

Most of the organisms considered heretofore have lived in the blood or in the gut of their hosts. *Ichthyophthirius* is a skin parasite, and as far as is known, lives in the skin and the layers immediately beneath it only. It attains a relatively large size, some being $\frac{1}{2}$ mm. to $\frac{4}{5}$ mm. in length. The parasites are somewhat pear-shaped when they are young (Fig. 52, *A*), but as they get older, they become more spherical. Myonemes are present on the body. The Ciliate possesses a rounded mouth surrounded by a thick lip, and this leads to a short cell gullet. The body contains a number of small, contractile vacuoles scattered in it. Cilia are present, but they are fine and delicate. The macronucleus (Fig. 52, *B*) is conspicuous, and in the trophic period of life is horseshoe-shaped, and lies in the centre of the body. The micronucleus is small and distinct in the young animal (Fig. 52, *A*), but as growth proceeds, the micronucleus seems to disappear, and its actual fate is not known with certainty.

The presence of *Ichthyophthirius* can be determined by the presence of numerous small whitish pustules on the skin, and amongst them small patches from which scales are absent and which sometimes are bleeding, owing to the breaking away of the parasite. The pustules are most common on the head and fins, but are also found on the eyes and gills, and in the latter situation they produce bleeding. In a very

heavily infected case the pustules run together, and form large sores all over the body.

The life-history of the parasite is not very simple. The young parasite is very small; it moves rapidly by cilia in the water for a short time, but is not able to live independently for long. Failing to obtain a host fish, it perishes. If a fish passes near the place

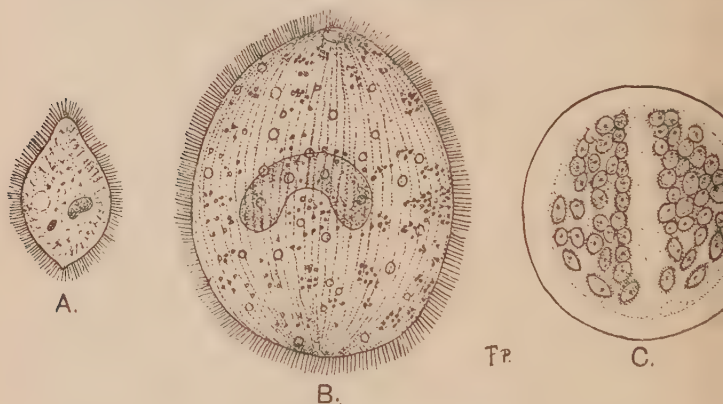


FIG. 52—*ICHTHYOPHTHIRIUS*

A, A young trophozoite with oval macronucleus and small micro-nucleus, and contractile vacuole; B, full-grown individual, showing large macronucleus, well-marked myophan striations, cilia, terminal cell mouth; C, a cyst containing numerous young parasites about to escape

where the tiny ciliate is swimming, the young parasite drops on to it and fastens itself to the skin. There it may remain, or it may force its way downwards to the deeper layers, so that, in time, a little wall of skin is formed around it, and the parasite lies in a pit formed by the irritated skin, and may be entirely enclosed by it. Growth continues at the expense of the host, giving rise to the pustules. When the

organism is fully grown, it forces its way to the surface and bursts through, leaving a small, gaping hole behind. Sometimes a mass of skin is torn away with it, producing larger sores, which afford a means of entry to *Saprolegnia* and other fungi so destructive to fish. The nearly globular parasite meanwhile sinks to the bottom of the stream or tank, and rests on the bottom or on pondweed. Multiplication then commences. The *Ichthyophthirius* first forms a thin gelatinous cyst for itself, and then its own body substance divides into two parts, which separate from one another within the cyst. The division is repeated, the number of divisions varying according to the size of the parent when it left the fish. As many as 256 daughter forms have been produced, but less than that number is not uncommon (Fig. 52, C). Sometimes individual cysts show peculiarities such as one only of the two parts produced by the first division continuing to divide. The cyst finally becomes much softer, and the young parasites swarm out from it and await the arrival of a fish, such as a trout or salmon, which may serve as a new host.

When the young *Ichthyophthirius* leaves the cyst, it is about $\frac{9}{200}$ mm. long, and it lives as a free-swimming organism for a short time. Should that time be prolonged, the young parasite dies. Advantage is taken of this fact in attacking outbreaks in aquaria. Fish known to be diseased are destroyed, and the seemingly healthy stock removed. The water is then drained from the infected tank, and the latter is exposed to light and air for three

days. It is then considered quite safe for use again. An alternative method is merely to remove the fish. Lack of food means death of the parasite, and as before, three days are considered enough to purify the tank. An outbreak in the open is far more difficult to treat, but cases are known in which the

disease was stamped out by netting the stream within certain limits and preventing the access of fish to the part treated.

So far, no mention has been made of any form of sexual manifestation, such as is seen among other Ciliates. Conjugation has, apparently, not been seen. According to one observer, nuclear division occurs in the young *Ichthyophthirius*, whose micro-

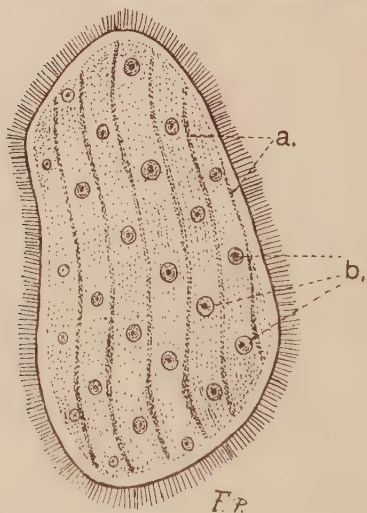


FIG. 53—OPALINA FROM THE RECTUM OF THE FROG

a, Myonemes; b, nuclei

nucleus divides into four. Of these, three perish and the fourth one divides again. What happens after this is somewhat uncertain. It is suggested that the two nuclei reunite, and so bring about a sort of self-fertilization or autogamy.

Opalina (Fig. 53) is perhaps the ciliate showing the greatest degradation due to parasitism in the group. Though it is multinucleate, it is in many ways a

negative organism, for it possesses no separate micro-nuclei, no cytostome, cytopharynx, or cytopyge, and does not reproduce like the majority of Ciliates. During summer and autumn one species parasitic in the rectum of the frog reproduces by a special method of division. There is a great increase in the number of nuclei, and the body divides also, so that two daughter forms are produced, each of which, after growing full-sized again, repeats the process. In spring the *Opalina* divide rapidly, but do not increase much in size before dividing again, so that they constantly become smaller. Finally, tiny forms, containing three to six nuclei, encyst and pass from the frog with the fæces. Further development occurs if the cysts are swallowed by tadpoles, when the organisms emerge from the cysts, divide into uninucleate individuals, which, later, unite together in pairs. The zygotes thus produced encyst, and within the cyst, nuclear fusion occurs, and finally the ciliates leave the cysts and grow into the adult forms.

The parasitism of the Ciliata has led to degeneration of the structures concerned with nutrition in many cases, and the limit of degeneration is found in *Opalina*. Correlated with the simplification of the vegetative structures, there is the great power of multiplication asexually within the host, and the production of cysts, either with or without sexual processes, to bring about the transference to new hosts. The Ciliata form an interesting group, the parasitic members of which may be shown, on further research, to be more numerous than is at present suspected. They are well worthy of extended investigations.

CHAPTER XIV

NASAL POLYPUS AND MUSCLE PARASITES

PARASITES affect peculiar situations at times, and while many of them have the power of invading almost any organ, a few seem to be restricted to very limited situations in which they can develop. One such situation is found in the septum nasi of man, for small masses protruding from the nasal partition of natives of India have been found to contain the parasite known as *Rhinosporidium kinealyi*. How the parasite reaches this position is still unknown, though the cases have been increasing in number since details of the organism were set forth in 1905. *Rhinosporidium* is probably not absolutely restricted in its distribution to India, for similar structures have been found in South America, and a short mention of an organism, described in 1900 under the name of *Coccidium seeberi*, may have related to the same organism, though detailed examination shows that there are a number of differences between the two.

The *Rhinosporidium* polypi are said not to be particularly painful, but it is obvious that they must interfere with health to some degree, if only from

the fact that the path to the air passages is impeded to some extent. The first polyp reported from India was about the size of a large pea. It had a short stalk by which it was attached to the mucous membrane of the nose. The structure has been compared with that of a raspberry, for it was red in colour with a number of small, whitish spots upon its surface. When the tumour was cut, a number of whitish specks could be seen within. These proved on examination to be cysts of a protozoal parasite. The cysts vary considerably in size. Each possesses a cyst wall, which varies in thickness in different cysts. Its outer wall is always firm and distinct, the inner limit being much less definite at times. Each cyst examined microscopically is seen to be filled with numbers of spherical or oval bodies, showing every gradation between small ones at the periphery to large ones towards the centre. Roughly, three zones of parasites can be distinguished, a peripheral set consisting of the youngest parasites in the cyst, an intermediate group, and a central oldest zone, each merging naturally into the other.

The youngest forms are difficult to detect. They are small, granular masses, and may be either ovoid or irregular, even amœboid in appearance. They are the early trophozoite forms. Such forms increase in size. Their outer layer becomes firm, and gradually small bodies with definite contours are differentiated. As each is destined to give rise to many spores, it is termed the pansporoblast. The formation of pansporoblasts progresses at the expense of the peripheral layer of protoplasm, which, however,

is at the same time growing, and thus causing the cyst, as a whole, to increase in size.

The pansporoblasts (Fig. 54) at first are single

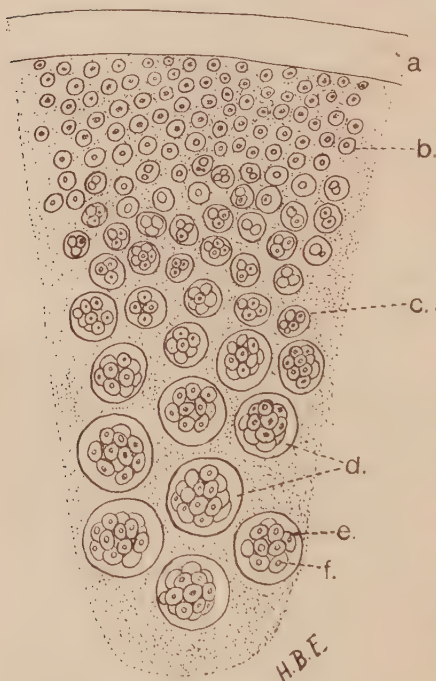


FIG. 54—RHINOSPORIDIUM: PORTION OF A FULLY DEVELOPED CYST

a, Cyst wall; *b*, young pansporoblasts in peripheral zone; *c*, intermediate zone of pansporoblasts; *d*, central zone of fully-developed spore morulae, and spores; *e*, spore; *f*, nucleus of spore

masses of cytoplasm, each with a nucleus, but they soon differentiate to form spores. The youngest pansporoblasts are still uninucleate (Fig. 54, *b*), but those of the intermediate zone (Fig. 54, *c*) soon show first one or two, then four or more spores; while in the oldest pansporoblasts (Fig. 54, *d*) about a dozen closely packed spores (Fig. 54, *e*) can be found.

When the cysts have reached a certain size, the growth of the peripheral protoplasm ceases, and as a result, no more pansporoblasts are formed. Each fully de-

veloped pansporoblast with its spores resembles a mulberry or morula. The spore is small and rounded, possesses a definite coat, and its nucleus is clear and distinct (Fig. 54, f).

Certain of the cysts have been found in a ruptured condition, whereby the spores have been liberated into the surrounding tissue, where it is probable that they recommence the infection. If such is the case, the pansporoblast might have the same function as the schizont of a *Coccidium* or the meront of *Nosema apis*. That they serve for the auto-infection of the host is almost certain, for though the tumours appear to have been removed completely, it has been found that they recur again, showing that some minute part of the parasite has remained behind, though every care was taken to ensure complete removal.

The method whereby the parasite reaches new hosts still remains unknown, and it would be of much interest if the life-history could be more fully investigated. It is highly probable that it is much more widely spread in India than was at first thought, and it may have considerable importance. In England it is well recognized that nasal and throat impediments have a great influence on the intelligence of children, and *Rhinosporidium* possibly has the same stultifying influence on the unfortunate people in whom it has been found.

The distribution of nearly allied parasites is of some interest. *Rhinosporidium* occurs in human beings living in tropical countries such as India. From India to the Antarctic is a wide stretch, yet

in certain small animals, known as *Cephalodiscus nigrescens*, a parasite, *Neurosporidium cephalodisci*, is found having a general resemblance to *Rhinosporidium* and belonging to the same group of organisms. It also has a remarkable distribution in the host, for it is present in the main nervous system, where it causes local degeneration of the nerve tissue, so that in time the parasites lie in oval spaces, wherein they multiply. The partly destroyed nerve matter forms a loose sort of capsule around the parasites. The smallest parasites are like amœbulæ. Having reached the nerve cord, they begin to multiply, when they look like irregular masses of protoplasm with two or three nuclei apiece. Several young parasites can be found in one space. Nuclear division rapidly proceeds, and oval bodies with many nuclei are produced.

A stage follows in which pansporoblasts are formed by protoplasm collecting around each nucleus and so producing a number of small, rounded, uninucleate bodies. The capsule thus becomes full of pansporoblasts, for they all seem to be formed simultaneously. The pansporoblasts increase in size and the parental material becomes much less. Soon the nucleus of each pansporoblast divides into a number of chromatin masses which form daughter nuclei. Each nucleus, with the protoplasm surrounding it, is a young sporoblast, and the collection of sporoblasts within the pansporoblast produces the appearance of a mulberry. Each sporoblast becomes a spore without much further change. The spores gradually pass out of the cavity around the parent organism, and

move away to start new infections in other parts of the nervous system of the host.

The organism is well adapted for parasitism in the special host in which it is found, but it has not been determined how it can be transferred from host to host. *Cephalodiscus nigrescens* is Antarctic, and consequently little material could be obtained for study, nor could living material be examined. But even were such available, the solution is not less easy. The angler fish, *Lophius*, often has microsporidian parasites belonging to the Glugeidæ on the bases of its nerves, and the fish is a common one, yet the mode of transference of the microsporidian is unknown. It is possible that the spores are set free when the host disintegrates after death, and that they are then ingested by other fish, but so far no proof of it has been afforded. Similarly, it has been suggested that the decay of the infected *Cephalodiscus* host liberates the spores of *Neurosporidium*. It would be easier for the spores of *Neurosporidium* to reach a new host than it would be for those of the parasite of *Lophius*, since the *Cephalodiscus* live in colonies.

Rhinosporidium and *Neurosporidium* are two members of a group where each pansporoblast produces numerous spores. A simpler set of allied forms is known in which the body divides into pansporoblasts, each of which forms a single spore. This second series forms one division of the group known as the Haplosporidia, *Neurosporidium* and *Rhinosporidium* being the second group. The simpler members of the Haplosporidia occur in worms, in the body cavities of Rotifers, and in some of the Crustacea.

Another group of organisms, showing some resemblances with the Haplosporidia and with the Myxosporidia and Microsporidia, is known as the Sarcosporidia. In England and on the Continent one of these organisms is found in sheep, the muscles of the œsophagus and its neighbourhood being flecked

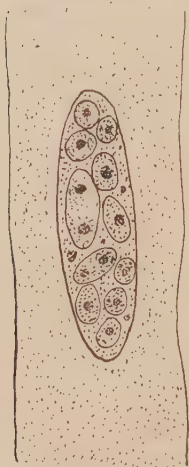


FIG. 55 — SARCOCYSTIS
FROM THE ŒSOPHAGUS
OF THE SHEEP

with white streaks and patches, which are colonies of parasites. A young parasite is shown in Fig. 55, from the œsophagus of a sheep. Horses and goats also may be infected. Pigs, too, are liable to attacks of Sarcosporidia. In Egypt the throats of slaughtered buffaloes show white masses of Sarcosporidia resembling blisters an inch and a half to two inches long, and the same condition is found in the roebuck. The parasite, *Sarcocystis tenella bubali*, is very common in the muscles of the tongue, larynx, and diaphragm, as well as in the skeletal muscles of buffaloes

in Ceylon. The use of the infected meat does not seem injurious to man, but the spores may cause irregular fever. In none of the above cases does the organism appear to have marked external ill-effects on its host. Sarcosporidia are also known in a very few reptiles, and some birds. Cases of sarcosporidiosis have been reported from man, the heart and

laryngeal muscles being infected, but how the infection was contracted is not known with certainty, unless the parasites were acquired in the food.

While the Sarcosporidia of domestic animals seem to be relatively harmless, the parasite that infests mice is remarkably fatal to the hosts. The organism produces a definite poison or toxin known as sarcocystin, which is rapidly fatal to the infected animal. Sarcocystin has been isolated from the spores, and shown to have fatal effects on animals.

In most cases the Sarcosporidia are found in the striped muscles of the body of the host, but they also occur in unstriped muscle, and even the heart muscle

may become infected, as in the African mouse bird, *Colius erythromelon*. The ability of the parasite to do harm depends on its power of spreading in the host. The more overrun the body of the host is, the more danger there is to its health.

Usually the occurrence of the Sarcosporidia is shown by whitish streaks or patches in the muscles. These streaks are known as Miescher's

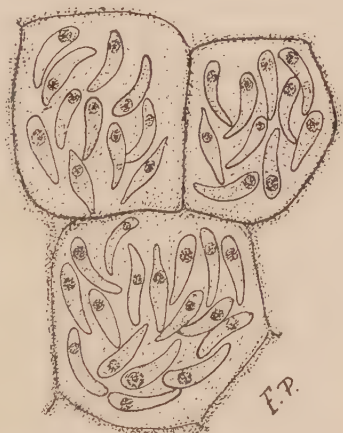


FIG. 56—PIECE OF BIRD'S MUSCLE SHOWING SPORES OF SARCOCYSTIS

Walls of chambers represented slightly diagrammatically

tubes. If a small piece of the tube be torn open or teased in a little salt solution, and then examined with the microscope, hundreds of small, oval or sickle shaped bodies are seen. These are the spores, for which the old name was Rainey's corpuscles. If sections of a Miescher's tube (Fig. 56) be examined, the spores are found lying in clusters in a series of chambers. Fine partitions separate one chamber from another. The outer layer of the Miescher's tube may show striations.

The spores themselves vary to a great extent, both in different hosts and in the same host. The *Sarcocystis muris* of mice has spores that are capable of rapid movements; others show but slight power of progression. Spores, no matter what host they belong to, are relatively fragile, and do not seem well adapted for resisting external conditions of life. Two types of spore have been found common in *Sarcocystis colii*, one narrow, one broad. The narrow form stains deeply, the broad one less deeply. A nucleus is present, and sometimes a few deeply staining granules may be scattered in the spores. An interesting point is that the character of the nucleus changes with the age and stage of development of the spore. Sometimes the nucleus has its chromatin evenly distributed; at other times it is concentrated to form a compact granule or karyosome, lying inside the nuclear membrane. A vesicle, which may be compared with the polar capsule of the Microsporidia, is often present near one end of the spore, and in some cases a minute protrusion has been seen from the spore in this region, suggesting

that there was a polar filament within. Such a filament, if present, has probably not been seen in its full length yet.

Multiplication of the spores occurs by longitudinal division, a feature of interest, since division of spores directly into two seems uncommon among these lowly organisms. All stages in this division have been seen by us in *S. colii* and in *S. tenella* of the sheep. The avian form certainly shows the division remarkably well. The stages of growth and extension of a Sarcosporidian in the vertebrate host are briefly as follows: Each spore contains an amoeba which finds its way into a muscle. The amoeba grows and its nucleus divides, thus becoming an elongate, multinucleate mass. Around each nucleus the protoplasm segregates, and a number of young pansporoblasts are formed (Fig. 55). At this stage pansporoblasts (sometimes called sporonts) may wander out and start new infections. Later, partitions or septa are formed between the pansporoblasts. Several spores are ultimately found in each chamber, having been formed from the pansporoblast (Fig. 56). A Miescher's tube is, then, a many-chambered structure containing spores, the spore formation taking place more especially at the ends or poles of the tubes. Old Miescher's tubes in section are interesting. The central part is often hollow, for the spores have been imprisoned there and have degenerated or disintegrated. Around the hollow chambers are others containing some more or less degenerate (or senile) spores. Beyond these are cavities filled with well-formed Rainey's cor-

puscles, while at the edge of the structure there are numbers of immature spores.

Though the Sarcosporidia have been known for many years, their life-history is still incompletely understood. The means whereby their hosts became infected has not been fully shown in any one case. More is known about the means of distribution of *Sarcocystis muris* than of any other Sarcosporidian. The first fact established was that healthy mice, by eating the flesh of diseased ones, could become infected experimentally after a long incubation period. Also, guinea-pigs similarly harboured the parasite after their food had been contaminated with spores from the muscles of mice. Cannibalism, then, may be responsible for the spread of *S. muris* among mice, at any rate to some extent. Mice fed on *S. tenella* from the sheep also became infected with this parasite. Again, if the Sarcosporidian was forced to change its host—for example, from mouse to guinea-pig—the parasite underwent considerable change in its appearance, so that, had not the circumstances been known, it would probably have been considered to be a new species.

An advance was made when Nègre fed mice with food contaminated with excrement from their infected fellows, and found that they became infected also. Even if the fæces were kept sixty days, they still retained the power of infection. This suggests a means whereby human infection has occurred. Accidental and undetected contamination of food by mice may have caused the ingestion of the spores by persons using the food, and so brought about their

infection. It has been shown by Erdmann that, should Sarcosporidian spores germinate in the intestine of a new host, their toxic sarcocystin is discharged and the neighbouring intestinal epithelium is destroyed. The spore-amœbulæ are thus enabled to find their way into the lymphatics, and later into the musculature.

Cannibalism may partly account for the transference of infection from mouse to mouse. Contamination of food also aids. But large cattle and buffaloes and fruit and insect-eating birds are not cannibalistic, and up to the present there is no proof that the spores of Sarcosporidia occur in their fæces. Some workers have suggested that flesh-flies and meat-flies can act as carriers of spores.

It has been stated that spores of *Sarcocystis* have been seen in the circulating blood. This report needs confirmation, but if true, it opens a new line of research, since some blood-sucking insect or arthropod (*e.g.*, a tick) may be responsible for the transference of the parasite from host to host. While it is difficult to conceive of insects or ticks being able to reach the spores embedded deep in the œsophageal muscles of a sheep or buffalo, the intake of spores, if present in the blood, would give relatively little difficulty. Far more investigation is needed on this point, and speculations on the subject are useless and premature.

CHAPTER XV

THE PARASITIC PROTOZOA IN RELATION TO THEIR ENVIRONMENT

IN the introductory chapter, mention was made of the types of Protozoa grouped according to their habits. They were either free-living or dependent in part on dead organic matter, or else they were parasitic. Examples of each group have been briefly noted in the succeeding chapters. It now remains to deal briefly with Protozoa in their relations with their surroundings.

The medium in which any organism lives has an enormous influence upon it. The degree of light to which it is exposed may alter the character of its nutrition, hinder or accelerate its movements, or may even cause its death. Heat is so closely bound up with light that the one may insensibly merge into the other. A change from one host to another, which is nearly allied (*e.g.*, two kinds of fish), may be fatal to the parasite. But the enormously greater change of a blood-inhabiting parasite from a "warm-blooded" host, such as a human being, to the gut of a "cold-blooded" animal, such as a tsetse fly, can be tolerated, and, more, is essential for the con-

tinuance of the race of the parasite. Some parasites may alter greatly in appearance if they are forcibly introduced into hosts other than their proper one. In other cases no change occurs. Certain Protozoa have been shown to inherit acquired characters, while in others transference to a new host seems to awaken the power to reproduce possible ancestral features, that may have been in past ages, but have gradually disappeared in the course of evolution.

Among the Protozoa, by far the greater number live and feed much as other animals do, but among the free-living forms, found usually in fresh water, there are a few that combine the modes of life of both plant and animal. Up to the present, no animal has been described, so far as is known, that has the power possessed by the plant, of using simple mineral constituents of the soil or of water alone as food. But a few, such as the *Euglena* found in pond-water, and the group of beautiful organisms, claimed by some as plants and by some as animals, known as the Algal flagellates, possess peculiar corpuscles, usually green, within their bodies. These contain some pigment, either chlorophyll or some substance having the same properties, and thus are able to absorb carbon dioxide, decompose it under the influence of sunlight, and utilize the carbon for building new protoplasm or for food materials.

Other Protozoa are unable to use inorganic food materials, nor do they prey upon living animals. Such are the peculiar Mycetozoa. The bulk of their nourishment is obtained from dead and decaying materials, such as bark of trees, tan refuse, dejecta

of other animals, etc. They are thus dependent indirectly on other living things for their support. Their mode of nourishment compares well with that of a fungus, such as a mushroom.

The greatest variation is found among the parasitic Protozoa. While the fungus-like method of nutrition does not, as a rule, depend on any one organism, those Protozoa that have become parasitic are often dependent on some special host or hosts, failing which they perish. Every Protozoön attached to a higher animal is not parasitic. Many fasten themselves to the outsides of certain Mollusca and worms, and such Crustacea as water-fleas, either by accident or because the position is one of advantage in obtaining food or shelter. When sedentary molluscs are used as hosts, shelter is the main end attained, while the active movements of the Crustacea through the water afford their protozoal guests numerous opportunities of obtaining suitable food and possibly extra quantities of oxygen. In neither case does any harm accrue to the host, and it is even possible that there may be advantages.

On the other hand, the *Ichthyophthirius* attaches itself to the skin of a fish, and by its action produces pustules and skin decay. The Protozoön alone is sufficient to cause death, but the open wounds that are caused by its attacks allow of the entry of bacteria and of fungi, such as the deadly *Saprolegnia*, and so hasten the end of the host. Thus Protozoa living on the outside of animals may be either harmless or extremely dangerous.

Similar effects follow the action of Protozoa in-

habiting the alimentary tracts of higher animals. But while there are some quite innocent Protozoa attached to the skin or external covering of other animals, probably no perfectly harmless Protozoön dwells within its host. Even those organisms like some Gregarines and *Opalina*, that seem to live mainly on waste materials in the food-canals of their hosts, may do injury in two ways. They may absorb small quantities of nourishment intended for their hosts, or they can bring about chemical changes in the effete matter present, which are detrimental to the animal harbouring them. The presence of the ciliate, *Blepharocorys*, in the food-tracts of horses and cattle causes the generation of gases, and produces intense mechanical irritation if numbers of the organism are present. Again, certain parasites may not only absorb raw food materials intended for their host, but may also utilize some of the products of digestion. A further stage in parasitism is seen in certain Gregarines, as mentioned in a previous chapter. Some merely absorb the fluid digested food from their host's gut, but others absorb the living substance of the host's cells in their neighbourhood.

Yet other Protozoa are found, forming a large proportion of those considered, in which simple entry for shelter has led to occupation for shelter and food, and has ended in complete adaptation to the parasitic habit. The *Amæba proteus* of pond-water is free-living. *Entamæba coli* absorbs waste materials and digested fluids alike from the human intestine. *E. histolytica* destroys the cells of the lumen of the alimentary tract, buries itself deep within the sub-

mucosa, and absorbs not only the contents of the cells near, but blood-corpuscles as well, while it can enter and destroy the liver substance. While *E. coli* is parasitic, it is not pathogenic to its host, thereby differing from *E. histolytica*. In each case, however, the Entamœba may suffer badly by the reaction of the host upon it. The accumulation of the products of decay in the intestine can react on the parasite and compel it to encyst in self-defence. Encystment may be a vital necessity for the continuance of the life of the parasite, but it also furnishes a way of escape when environmental conditions become unfavourable.

The fluids of the body—blood, lymph, bile, and cerebro-spinal fluid—all serve as habitations for parasites. The malarial parasites retain the evidences of their action on the blood-corpuscles in the masses of melanin pigment present in them, melanin being produced from the hæmoglobin of the blood. The presence of Spirochætes in the blood brings about an alteration in the relative numbers of red and colourless corpuscles, and many protozoal parasites (whether occurring in the blood or gut), as well as parasitic worms, cause marked reactions in the blood. The lymphatic glands of sleeping-sickness patients become enlarged and hard, and the trypanosomes occur both in them, in the blood, and in the cerebro-spinal fluid. The parasite itself often shows no marked evidence of the host's action in its blood form, though the reaction of the host is sufficiently potent to compel its disappearance from the circulating blood, and to cause the formation of the latent bodies. The

exact means by which trypanosomes become deadly is not known with certainty, but it has been claimed that a poison—trypanotoxin—has been prepared from them. Their mechanical action in blocking minute capillaries, and their infiltration into various spaces such as those in the cornea of the eye, are distinctly of importance.

The effect of Myxosporidia in the gall-bladders of fishes has already been mentioned. There is multiple action here. Mechanical irritation causes mucus formation. The action of the parasites produces chemical alteration of the bile, and consequent on this, digestive derangements and emaciation of the host result.

Tissue parasites are more dangerous than those free floating in such fluids as the bile and urine. Not only do they destroy the tissue that they infect, but they also produce cavities or lesions that permit of the entry of various fungi and bacteria. These latter organisms, so long as they are present in the alimentary canal only, may be quite harmless, but they can have serious effects when they gain direct access to the tissues. The dissolving and destruction of living tissue and admission of other organisms are not the sole means whereby the tissue parasites do damage. They can gain access in some cases to fine tubes within the infected organ, and render such safety channels as the kidney tubules quite useless by blocking them with masses of their bodies or spores. The amoebæ that cause liver abscess, and the *Eimeria* found in the liver in blackhead of turkeys, both destroy the tissue and interfere with other organs in-

directly, for more work is put upon such organs owing to the failure of the liver's action. Parasites such as *Schizotrypanum cruzi* and *Leucocytotharax funambuli* that form cysts in the lungs of their hosts interrupt the aeration of the blood, and hence produce some degree of anæmia.

In conformity with the mode of life of parasitic Protozoa, it is most important to them that the life of their host should be prolonged. They are dependent on it both for food and shelter, and in some cases the death of the host brings about the destruction of the parasites. But once a parasite is established in its host, its need for shelter and food is at an end, and consequently the organism ceases to provide elaborate apparatus for the capture and digestion of food. Even parasitic Ciliates reduce the size of their cell mouths and gullets and decrease the number of their cilia. But with decrease in complexity of organization, there comes also an increase in the powers of reproduction. Large numbers of offspring are necessary in order to maintain the race. They may be destined merely to overrun the host animal or to pass from one host to another, the latter passage being far the more difficult and dangerous. The ideal host for any parasite, naturally, is one that can tolerate the presence of the intruder for the longest period without ceasing to afford nourishment for the latter by the impairment of its own health. Once the reaction of the host against the parasite has commenced, and the protozoön has produced resistant forms, the death of the host may provide the channel of escape for the

parasite, and by the decay of the larger animal, the resistant forms of the smaller one may be set at liberty.

Even then, there are many perils to the parasite. The resistant bodies may be set free, but in the wrong environment. They can lie dormant for long periods, but if they cannot get in contact with a new host of the right sort, death results. Many parasites are harmless to all races of animals except one. They are specific to one host. Others are capable of living in several hosts, more or less indifferent as to which one they infect. The *Myxidium* of marine fishes is a good example of such adaptability. In contrast there is great restriction of hosts shown by such interesting parasites as the *Aggregata*, found in cuttlefish and octopus. In the bodies of these particular molluscs the parasites form large numbers of gametes, which, after fusion, produce spores. Some of these spores are voided with the excrement, others remain in the body of their host. When a squid or octopus is dead, it is a favourite meal of many sea dwellers—fish, other molluscs and crabs alike. Should a special crab eat the infected mollusc, it absorbs also spores of the *Aggregata*. From each spore, three or more sporozoites issue, commence to attack the crab, and form large cysts that bulge into the body cavity. They form internally myriads of minute, club-shaped merozoites, so arranged that in section they resemble large daisies. Crabs are among the most common contents of the stomachs of octopus and cuttlefish alike, and in the process of digestion the cysts are broken open and

merozoites set free, and the parasite is in a position to infect the mollusc. The chances of the successful transference of the *Aggregata* from crab to mollusc and *vice versa*, are fairly good, though the final difficulty of transmission is that special crabs allow of the development of *Aggregata* from particular molluscs only, as a rule. It is likely that the enormous numbers of merozoites in the crab and of spores in the mollusc are direct adaptations to meet the difficulty of transference.

The effect of change of host on the life of a parasite may not be very marked. The parasite itself shows great adaptability to new conditions, and it is able to cope with chemical differences of the medium around it, differences of temperature and of pressure. The threefold adaptation necessary is carried out by some parasites without much change of form or manifest alteration. *Trypanosoma gambiense* passes from the blood of man into the gut of the tsetse fly *Glossina palpalis*, and *T. rhodesiense* similarly into the digestive tract of *G. morsitans*, whence both make their way to the salivary glands. There is a great change from the fluid environment of the living human blood to the chemically altered and partly digested blood in the stomach of the tsetse, and again to the salivary glands of the fly. Accompanying this change, there is a fall in temperature and also a difference in the pressure exerted on the trypanosomes. But in the intestine of the flies no markedly essential change of form of the parasite is observed, the trypanosome appearance being maintained, though changes in size occur. However, a temporary crithidial stage

ensues in the salivary glands of the tsetse, preceding the resumption of the stumpy, infective trypanosome stage.

The development of the malarial parasites affords an example of the necessary transference of parasites to a totally different environment, in order to complete their own development. While sex forms commence to develop in the human or bird victim, so far as is known, they never reach maturity. That only occurs when they pass into the gut of an Anopheline or Culicine, as the case may be. There are many factors involved. Whether it is merely the decrease in temperature that is directly responsible for the production of sex forms and ultimately cysts, or whether chemical stimulation is the cause, remains to be proved. Probably both factors help, as does also the degree of concentration of the medium.

The development of sex forms is frequently independent of change of host. Coccidia produce their sex forms within the same host as the asexual forms, and it seems that the diminution in nourishment, together with chemical alterations in the food available—the indirect result of the action of the parasite—are largely responsible for the production of the sexual forms of the *Eimeria*. The nutrition seems of paramount importance in these cases. When there is an abundance of food, schizonts only are produced. When the host is overrun with parasites, and the food-supply is failing, then the sexual phases of the parasite are formed in order to produce stages capable of resisting extracorporeal conditions, and subsequently becoming transferred to a new host.

The adaptation of a parasite to different but nearly allied hosts, without change of form occurring, is used in the study of blood parasites such as *Spirochætes* and *Trypanosomes*. Thus it is known that animals such as mice, rats, and guinea-pigs can harbour flagellates or *Spirochætes* in their blood without causing change in the organism concerned. The possibilities of the cure of human complaints by the action of drugs can thus be tested, and already much alleviation of human suffering has resulted from such researches. At the same time, the parasitologist cannot but remember the enormous powers of adaptation shown by *Spirochætes* capable of living in the blood of man, monkeys, rats, mice, and guinea-pigs, and finally in the gut, body cavity and Malpighian tubules of the agent of transference—a tick or a louse. Due regard must be paid to morphological variation, in order to avoid errors of interpretation.

Change of host can occur quite naturally among the *Spirochætes* of molluscs. The oyster and the edible *Tapes* — “clovisses” — live together in the Mediterranean, and *Spirochætes* from the one can pass into and live in the crystalline style of the other. The style of the oyster is far less firm than that of the *Tapes*, and as a result, *Spirochæta balbianii* adapts itself in the *Tapes*, and divides more frequently, so that somewhat thinner forms are produced than is usual in the organism in the oyster. Morphological variation is thus one result of difference of host.

All parasites are far from being so complaisant. *Trypanosoma lewisi* lives in the blood of rats. When this organism is transferred to a snake, it seems

to disappear, or, at any rate, very few specimens are seen. When blood from the snake is inoculated into a clean rat, then trypanosomes reappear in the rat, but they are not like those originally inoculated. It seems certain that, in such a case, changes in form and virulence of the trypanosome have occurred. What is the explanation of the change? One of the suggestions put forward is that the rat trypanosome has merely undergone certain changes that have enabled it to become different when returned to its original host. While this is possible, it is probable that other explanations of the change of form and of virulence will be afforded later, when the biochemistry of trypanosomiasis in vertebrates and invertebrates has been more fully investigated.

Among lowly organisms, plasticity and power of adaptation to different conditions are very great, but like higher animals, most of the Protozoa retain many of their ancestral characters. The external form may be slightly modified, or the internal structure may be changed temporarily, but often a short period is sufficient to bring about the restoration of the original form. Some very interesting and instructive cases are known of new "races" of trypanosomes arising owing to the action of certain drugs on the hosts harbouring them. In these cases the blepharoplast has disappeared. The organisms then show only a large nucleus. They move actively, increase in numbers, and behave in an ordinary manner. But the descendants of the blepharoplast-less trypanosome do not revert to the ancestral type for many generations, and consequently the organisms

may be said to have inherited the acquired character of lack of blepharoplasts, and to be able to perpetuate the same, though the excitant cause of the peculiarity, the action of some drug, *e.g.*, pyronin, may have been removed. A natural parallel occurs in *Trypanosoma equinum*, of "mal de caderas" in horses, in which parasite the blepharoplast is either absent or very minute.

The degree of virulence of parasitic Protozoa towards their hosts varies. If a strain of deadly parasites remains deadly continuously, its very violence may possibly pave the way for its own destruction. The lack of hosts may be sufficient to cause it to disappear. Alternatively, as with the more virulent form of sleeping sickness, parasites are maintained in reservoirs such as wild animals that tolerate the trypanosomes, and are none the worse for their presence. Some trypanosomes when inoculated into a succession of rats become weaker in their virulence as time goes on, but a passage to a guinea-pig and then again to rats has restored their lethal power. New problems are thus ever being presented to the parasitologist.

Among higher animals a certain amount of light seems essential to their well-being, but the natural condition of most parasitic organisms seems to be one of darkness. The body cavity in which a Gregarine lives, the cæcal tissue harbouring coccidia, the blood containing trypanosomes, the gut of an insect with its parasitic flagellates, all are relatively opaque and dark. Bright light is an annoyance to many parasites; and though continuous exposure

to strong light results commonly in a certain amount of toleration for it, yet the shelter of débris is usually sought by parasitic Protozoa, which burrow into it in an endeavour to reach the desired darkness. Green light is less harmful to many flagellates than is white light, and they live longer therein. Violet light, on the contrary, stimulates them to intense activity, resulting in rapid death from exhaustion. The action of red light varies considerably, in some cases accelerating movements, in others slowing them, while blue light seems neutral.

The colour of Protozoa in relation to parasitism is a subject concerning which very little is known. Many of the Gregarines and allied parasites are frequently opaque and densely granular. In our investigations of Gregarines from the *Scolopendra*, it was easy to pick out the dense white, opaque parasites from the gut without using any lens. Living Trypanosomes and Hæmogregarines often show a faint bluish tint, and it has been suggested that this is possibly due to a dilute pigment of an unknown nature. Green coloration, except among the Algal flagellates, is comparatively uncommon, since the absence of light often precludes its formation.

Interesting pigment-grains occur in some of the Myxosporidia in the gall-bladders of fish, the grains varying in colour from green to brown. Sometimes they form clusters, at others they lie singly in the cytoplasm. It is probable that they consist of altered bile pigment. No obvious value seems to be attached to colour production among the parasitic Protozoa.

Parasitism in the past affords scope for many interesting speculations. Time was when the earth was populated with enormous mammals, huge flying reptiles, giant primitive birds, and large Amphibia. All now have vanished, and their fossilized remains or impressions are all that persist to tell the secret history of the "giant" era. To what causes can the wholesale disappearance of such a wonderful fauna be ascribed? Physical changes in the earth alone are insufficient to account for the vanishing of all these animals. The evolution of chemical fumes would tend to kill all forms of life at about the same time, and there is no good evidence of this. One recent suggestion is that the disappearance of these mammoth creatures from the earth's surface was due to the activity of malarial parasites, trypanosomes, or other parasitic Protozoa. When we realize that within the last century human tribes have almost disappeared as the result of the action of parasitic Protozoa, the hypothesis does not seem entirely unlikely. Reverting to the opinion that the newer the parasite is to its host the more deadly it is, would it not be likely that the intensity of virulence in those early days would be enormous in comparison with what it is now? The fate of horses and cattle in the "fly belt" of South Africa is a striking example of the terrible effects of trypanosomes in causing the disappearance of fauna in a short period; and in the dark ages of the past, when parasitism was probably newer and the field was wider, it must have been infinitely more drastic than at the present time.

CHAPTER XVI

ECONOMIC IMPORTANCE OF THE STUDY OF THE PROTOZOA

PROTOZOA and man have been said to represent the extremes of organization in the animal world. They certainly afford striking contrasts. The structure of the Protozoön is very simple, that of man most complex. The concentration of functions in the protozoal organism is infinitely superior to that of man, where specialization has reached almost its finest limits. The career of man, the complicated, is often determined by that of the simple Protozoön, and great human enterprises have failed because of the intermediation of these unsuspected foes in the animal world. The economic importance of the Protozoa is shown in relation to the health of man, to his food-supply, to his means of transport, and even to the place in which it is possible for him to make his home.

The human body is subject to the attacks of many Protozoa. The skin may be invaded by various species of *Leishmania*, producing disfiguring sores, or by *Spirochætes* that lead to extensive ulcerations. The alimentary canal throughout its length may be

parasitized. Spirochætes and Amœbæ are found in hollow teeth; Entamœbæ invade the intestine. *Trichomonas* and *Lambliæ* among the flagellates, and *Balantidium* and *Nyctotherus* representing the ciliates, as well as Amœbæ, are associated with diarrhœa and dysentery. The blood can harbour several species of malarial parasites, spirochætes, and trypanosomes, the latter also finding their way into the nervous system. The tissues may be infected by Entamœbæ in liver abscess, Sarcosporidia in the muscles, Coccidia in the bowel, and stages of parasites, such as *Trypanosoma cruzi*, found lodged in the tissue of the lungs, as well as in other situations. Nor does this exhaust the list, for nasal and aural tumours can be produced by protozoal agency. It is suspected that many complaints, such as smallpox, trachoma, hydrophobia and measles, the causal agents of which are little understood, are due to the agency of Protozoa as yet incompletely determined.

The importance of the study of the Protozoa in relation to man's health is undoubted. The enormous losses of life in the various attempts to cut the Panama Canal are witnesses of the malignant power of various Protozoa. The sacrifice of many lives in developing the resources of Africa is evidence of their effect. The retarded development of parts of South America, India, and China is the result, not of lack of attempts, but of the presence of protozoal diseases, that are dispersed actively by the agency of various insects and ticks.

The aims of medicine may be summed up as making the human frame healthier, and rendering

the conditions of life easier. Both are brought about in a large measure by the study of the parasitic organisms that infect man and of the means whereby disease is spread from man to man. Had it not been for the researches of Laveran, who discovered the malarial parasites in the blood, and the classical work of Ross on the mosquito transmission of malaria, full preventive measures could not have been so easily devised. Dutton and Forde's discovery of *Trypanosoma gambiense*, followed by the inculcation of the tsetse fly, *Glossina palpalis*, gave a basis both for preventive measures and for direct treatment. The economic importance of these discoveries is enormous, for such regions of the world as West Africa and the Congo possess many of the productions regarded as necessities of our present civilization, together with a most fertile soil, capable of great development. Yet, unless some means of preventing sleeping sickness be devised, these countries are destined to remain relatively undeveloped, the possession—and often the grave—of nations among whom dwindling has progressed in many cases. The Congo has claimed many victims ere this, not only from trypanosomiasis, but from spirochætosis, or tick fever. It has only been by patient and laborious work, that the mode whereby the tick infects people and also passes on the Spirochætes to its own offspring, has become known. Both spirochætal tick fever and yellow fever cost their early investigators their lives—sacrifices for the cause of suffering humanity.

The direct effects of the protozoal diseases of man,

as just mentioned, are not limited to the numbers of deaths actually due to them. There are recoveries or partial recoveries known, and such cases remain usually with a lowered vitality. The race thus tends to become enfeebled, and often lacks the initiative to better its conditions, so that after an epidemic of disease there seems to be a tendency to degeneration, rather than to improvement, among the survivors of the more primitive tribes.

The great importance of the parasitic Protozoa in relation to human disease is evident, and they are also important in connexion with the food of man. When redwater and coast fever were discussed (Chapter IX.), the monetary losses due to the death of cattle in the United States alone were estimated at £8,500,000, and that sum would be enormously increased were the world's losses due to protozoal cattle diseases estimated. Redwater fever is a serious menace, coast fever cuts off both food and means of transport; but they are not alone. Surra, in India, due to *Trypanosoma evansi*, causes much damage. Nagana, in South Africa, kills cattle and horses alike. Sheep perish from the attacks of *Babesia ovis*. Goats die of heartwater, which is spread by ticks, and is considered by some to be due to an undetected Protozoön. Coccidiosis slays cattle in East Africa, and the same disease destroys game birds and poultry, such as fowls and turkeys, while rabbits also are badly infested in some places. Spirochætosis is rampant among fowls in Egypt and the Sudan, and epidemics among geese and ducks occur in Russia. Apart from frequent deaths,

the value of such birds is greatly reduced, for they become much emaciated, and have little nutritive value. Fish furnish food to many persons and even nations. Here, too, man is affected by Protozoa, for the Myxosporidia are notorious parasites of fishes, sometimes producing tumours or sores, and at other times causing malnutrition, and thereby lessening their value as food. Certain Microsporidia also affect fish in a similar way. The problem of fish diseases is one demanding more attention than it is receiving at present, and many hitherto inexplicable deaths of fish are probably due to protozoal parasites. This has been our experience in recent outbreaks in England among freshwater fish, such as dace, bream, and salmon. The extermination of the barbel from the south of England, though not nearly so important as the outbreak in Germany, was due to a *Myxobolus*, and destroyed a source of food valued by the peasantry in the south.

The cost of living in England is one of the most serious problems that has to be faced. At the present time, the cost of frozen meat in England is almost what was paid for the freshly killed home product a quarter of a century ago. The effect on prices of the stoppage of the home-supply from a very limited area, due to an outbreak of "foot and mouth" disease (probably due to a minute Protozoön), has been most marked. The failure of stock from a great exporting country, such as the Argentine, has dire effects on nations restricted in their home supplies like Great Britain and Germany. Practically all kinds of animals used for food in England to-day

may suffer from protozoal parasites in some part of the world. Fortunately, in many cases, the loss can be controlled to some extent by precautions exercised against the transmitters of the disease.

Animal parasites affect man in another direction. Were it not for the big game that act as reservoirs of *Trypanosoma gambiense* and *T. rhodesiense*, without themselves being harmed, the prevalence of sleeping sickness in man probably would be reduced. *Balan-tidium coli* from pigs is spread to man by the cysts that pollute food or drink. These cases are clear, but not so numerous as are the examples of parasitic worms that spend one part of their lives in domestic animals, especially cats and dogs, and the remainder in human beings.

The study of parasitic Protozoa in relation to the food-supply of nations is, then, of the utmost economic importance. The work is both tedious and expensive, and in England there are not the opportunities for such investigations as are afforded in America. There, a great State Department—the Bureau of Animal Industry—devotes the whole of its attention to the study of the people's food-supply, the suppression and cure of animal diseases, and the improvement of the methods of production of stock.

The transport problem, again, brings to the fore the importance of the study of the parasitic Protozoa. Cattle are used for transport as well as food. Horses, mules, and camels, are constantly employed for the conveyance of goods where railways are distant or inconvenient, and waterways not available. Agricultural operations in many districts, it is true, are

now largely performed by mechanical apparatus, yet even among these the horse finds a place. Motor power has not yet wholly supplanted the horse and mule in the moving of guns and similar implements of warfare; nor has it yet superseded the camel as a means of crossing the shifting surface of the Sahara. Yet these animals most used in transport may be afflicted with trypanosomiasis in tropical and sub-tropical countries. Even as near to England as Spain and the South of France, trypanosomiasis in the form of "dourine" can play havoc with the baggage animals, particularly mules and horses, that cross and recross the mountainous passes of the Pyrenees, and are the main means of transporting local agricultural produce between the two countries. The "nagana" of Africa, due to *Trypanosoma brucei*, is very serious, for it is spread by *Glossina morsitans*, one of the most ubiquitous of tsetse flies. It is invariably fatal to horses, donkeys, and dogs, and a very small proportion of the cattle infected with it recover. The problem of transport is serious in some parts of India, Burma, Mauritius, and the Philippines, for "surra," due to *Trypanosoma evansi*, infects horses, mules, camels, and cattle alike, and with fatal results. The biting flies *Tabanus* and *Stomoxys* are responsible for its spread, and Mauritius animals became infected by stock imported from India. South American horse-breeding suffers because of the presence of *T. equinum*, that produces the disease known as "mal de caderas." The exact means whereby the malady is spread from horse to horse is unknown, but it has been found that the

same parasite kills also the large native semi-aquatic rodent known as the capybara. Dogs eat the capybara and become infected thereby. It is suggested that fleas contract infection from the dogs, and pass from the dogs to the horse. It has been established that infected dog-fleas can pass on the disease to rats and to other dogs, and it is possible that they can do the same to horses. *Stomoxys* also has been suspected, but not proved, to transmit the parasite.

Transport by cattle is common in West Africa, and *Trypanosoma vivax* is responsible for much destruction, not only among them, but among sheep, horses, and goats also. *T. brucei* is also present, and both are so fatal to horses in Nigeria that in many districts the Government refuse compensation to their officials for the loss of their animals dead of trypanosomiasis, even when they have been used solely for official duties. Transport animals and cattle intended for food in Nigeria become infected in a short time, and when the natives detect sickness, the animals are slaughtered by the roadside, and cut up and sold at a great loss to their owners, and this necessarily causes great interruption to the progress of trade in the country.

Transport both by horses and cattle is interrupted also by diseases due to the redwater group of organisms. *Babesia bovis* and *Theileria parva* have already been discussed in some detail (Chapter IX.). Mention, too, may be made of the diseases of horses, mules, donkeys, and zebras in Africa, and of the first three in some parts of Europe, due chiefly to the

organism known as *Nuttallia equi*, which seems to combine both the features of *Babesia* and *Theileria*.

Intercommunication between different districts is largely interrupted, then, by the loss of transport animals, and nowhere is this more seen than in districts in the tropics newly opened up to commerce or to civilization. When there was little communication between the different tribes in Africa, certain trade routes only were used, as experience had shown that others, often more direct, were fatal to cattle. The advent of the European official and trader changed this. Their work took them into the "bad" places, with the inevitable ill-effect on their transport animals, and also increase in the evil, since these animals were capable of passing on the virus to tsetse and other flies in hitherto uninfected districts. Thus the trader has been said to have laid a trail of disease from the coast to the interior, and the problem of the development of many parts of tropical Africa is intensified.

Human beings, food animals, transport animals—all are alike affected by the presence of minute Protozoa, and thus certain districts are almost forbidden ground to white men. Yet overcrowding is rampant in many cities of the Old World, and room is needed for their surplus population. The progress of manufactures demands many products only obtainable from semitropical and tropical lands. The food-supply is one of the most pressing necessities of the present time. And, in contrast, immense districts of the world are underpopulated, yet fertile and richly productive, capable of supplying all the

needs, were it not for the presence of disease due to various parasitic Protozoa. What, then, is the remedy for this state of affairs? The solution seems twofold. There must be an increase in the study of the parasitic causes of disease, combined with active preventive measures against the transmitters of the same. Malaria has been largely conquered by systematic attention to anti-mosquito measures and the use of quinine. Yellow fever in the West Indies is now no longer a constant feature since the determined onslaught on the breeding-places of the *Stegomyia* was made. The United States does not suffer such bad losses in cattle as it did a few years ago, for the quarantining of stock against ticks has produced a marked effect. Even human trypanosomiasis has declined in places since the natives were removed from the banks of streams frequented by *Glossina palpalis*.

Much, then, can be accomplished, but still an enormous amount of instruction is needed before communities as a whole will take action, and the plea of the scientist may aptly be described as that of the voice crying in the wilderness. The amount of resolution displayed by the ignorant in refusing to carry out the simplest of sanitary reforms is amazing, though it is equalled by the determination to have nothing to do with anything that has not been sanctioned by long custom. Until education on subjects so intimately connected with the welfare of the Imperial Dominions as the life-histories and significance of parasitic Protozoa is much more widely diffused, the rate of progress will be slow.

Throughout this little book an endeavour has been made to emphasize the importance of the study of the parasitic Protozoa to our nation, which is so dependent on its colonies for its daily needs, and has so vast a responsibility as the "Empire on which the sun never sets." The biology of parasitism should have a worldwide interest, not only in connecting the past with the present, but extending from the present away to the dim horizon of the future.

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